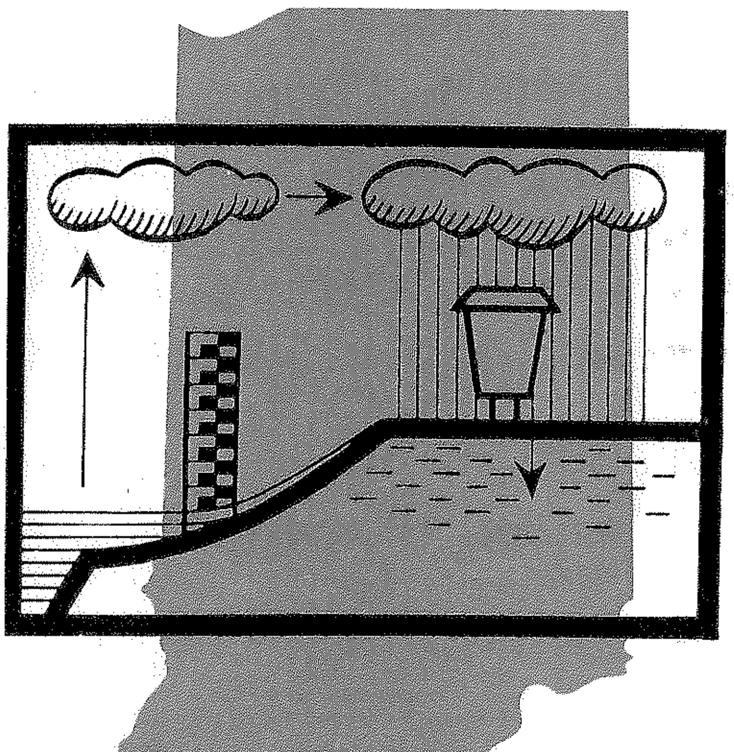
TECHNICAL REPORT NO. 148

EFFICIENCY OF RESOURCE USE UNDER SMALL-SCALE IRRIGATION TECHNOLOGY IN NIGERIA



by

Patrick Osaretin Erhabor

June 1982

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

EFFICIENCY OF RESOURCE USE UNDER SMALL-SCALE IRRIGATION TECHNOLOGY IN NIGERIA

by

Patrick Osaretin Erhabor

June 1982

Purdue University Water Resources Research Center

Technical Report No. 148

The author wishes to express his profound gratitude to Dr. William L. Miller for his valuable suggestions and insightful comments on this report --to Dr. Earl W. Kehrberg for his conceptual ability, and general thoroughness; to Dr. Bruce McCarl for his initiative and expertise in linear programming; and to Drs. Deborah Brown and Dr. Sheng-Cheng Hu for their helpful comments and suggestions. Also, the author wishes to thank Professor George O. Abalu and the staff of the Department of Agricultural Economics and Rural Sociology, Zaria, Nigeria, for their helpful comments and suggestions on the research proposal.

The author wishes to thank Ahmadu Bello University, the Ford Foundation, and the Institue for Agricultural Research for funding the research that led to this report.

Abstract

The current drought in Northern Nigeria, the declining countribution of agriculture to the GDP, increasing food imports and the need for agriculture to play a greater role in the socio-economic development of the country have intensified interest in irrigation development in Nigeria. Although the trend of irrigation development has been mainly directed towards large scale irrigation, this research was designed to study the small scale lift irrigation methods of applying water (shadoof and pump).

It was hypothesized that promotion and improvement of these systems might contribute to more efficient agricultural production. This study was, therefore, designed to estimate the economic returns to small scale shadoof and pump irrigation systems and to indicate implications of these returns for research, extension, and government policy.

The analytical framework chosen for this analysis was a linear programming model. A major problem of using the LP model was that the farmers intercropped, making it difficult to assign inputs used to a specific crop. To cope with this problem, regression analysis was used in the specification of small scale irrigation linear programming activities. The Production Possibility-Convex Approximation Model (PP-CAM) used in this study is a new and potentially useful technique for analyzing resource use under intercropping. The data necessary to estimate the coefficients or parameters of the model were obtained from 114 irrigation farmers (104 shadoof and 10 pump) in Ringim LGA, Kano, Nigeria during the 1978/79 irrigation season.

The results of the study indicated that the returns to irrigation farming with the shadoof and pump irrigation technology is quite high. Thus the benefits from promoting these small scale lift devices are worthy of consideration by policymakers interested in increasing agricultural output. A major barrier identified as limiting the expansion of irrigated land area was unavailability of water. Although there is sufficient ground water, the amount currently accessible for irrigation with pumps and shadoofs is limited. Investment in wells and ponds could increase availability. Lack of timely repair service hinders adoption of pump irrigation at present.

Table of Contents

INTRODUCTION

For many years the prospect of irrigation development has been central in the activities of people engaged in long range planning for agriculture in Nigeria. In the first National Development Plan, 1962-68, agricultural planners in Nigeria requested the FAO 'To make an intensive study of the country's agricultural potentials and to draw up a scheme of priorities for development' [37]. The result of FAO research is summarized in their final recommendation that

> "There is a vast potential for improvement of agriculture in Nigeria. Full realisation of this potential can result only from a long-range programme since it will depend upon the development of surface and groundwater resources for irrigation...." [21]

Based on this recommendation the Federal Government of Nigeria has reiterated a commitment to irrigation development as reflected in the statement contained in the second and third National Development Plans that

> "Full exploitation of the agricultural potential of the country is only possible if its water resources are developed for irrigation which will not only permit multiple cropping but also ensure sufficient water during the growing season of the crops" [38, 39].

This commitment to irrigation development was preceded by attempts to irrigate land, particularly in the northern part of Nigeria.

Historical Development

The first survey of irrigation potential in Nigeria was carried out in the North prior to 1918 by Colonel Collins, a military engineer with experience in India [46]. A chronology of irrigation development in Northern Nigeria is presented in Table 1.1. The study by Collins resulted in the impounding of flood waters from Sokoto and Rima River Valleys in order to irrigate plots of land by 1918. This project was destroyed four years later by the flood of 1922 and never reconstructed.

The first attempt to irrigate a large area was the Kware project, which followed the appointment of Collins in 1925 to study the Rima, Sokoto and Zamfara Valley systems as shown in Figure 1.1. As a result, the Shalla Stream was canalized and a bund built to protect an area from flooding at Kware and to furnish water for irrigation through the Shalla Canal. By 1929, 243 hectares were developed for perennial irrigation, although the estimated 13.25 hectare centimeters/hour available would have been adequate for irrigation of 1052 hectares. The crops grown were sugar cane, cassava, sweet potatoes and maize but yields were low. In 1940, this project, like the first project discussed above, was destroyed by a flood. The major reasons advanced for the failure of these early irrigation attempts were: (1) inadequate technical knowledge of water control and agricultural practices, (2) lack of knowledge regarding the profitability of various crops when irrigated, and (3) lack of the needed inputs, particularly the oxen that are required by the Eastern (India and Asia) methods.

Table 1.1. A Chronology of Irrigation Development in Northern Nigeria.

Date	Consultant	Water Source	Construction	Project Location	Hectares Irrigated	Crops Grown	Current Status
1918-25	Col. Collins	Sokoto and Rima River Valleys	Impound water behind dike	Sokoto Area	Small plots	Sugar cane, cassava, sweet potatoes and maize	Destroyed by flood in 1922
1925-40	Col. Collins	Sokoto, Rima and Zamfara River Valley	Canals and a bund for water impoundment	Kware Project	243	Sugar cane, cassava, sweet potatoes, maize and wheat	Destroyed by flood in 1940
1949	Irrigation Division, IBRD and NEDECO	Niger River Valley Streams	Impound water behind dike	Niger Valley Project (Mokwa) and parts of Sokoto Province	405	Rice	Parts still operational
1950-59	Irrigation Division	Niger River Valley Streams	Impound water behind dikes	Niger Valley Projects (Badeggi and Edozhighi)	405-810	Rice	Still operating
1956-65	USAID, USAID NEDECO FAO	Yobe River Hadejia Riv. Ebeji River Rima River	Installed pump near river	Daya & Abadan Kano Gamboru Wurno	384-425 473 400 162	Rice and wheat	Still operating

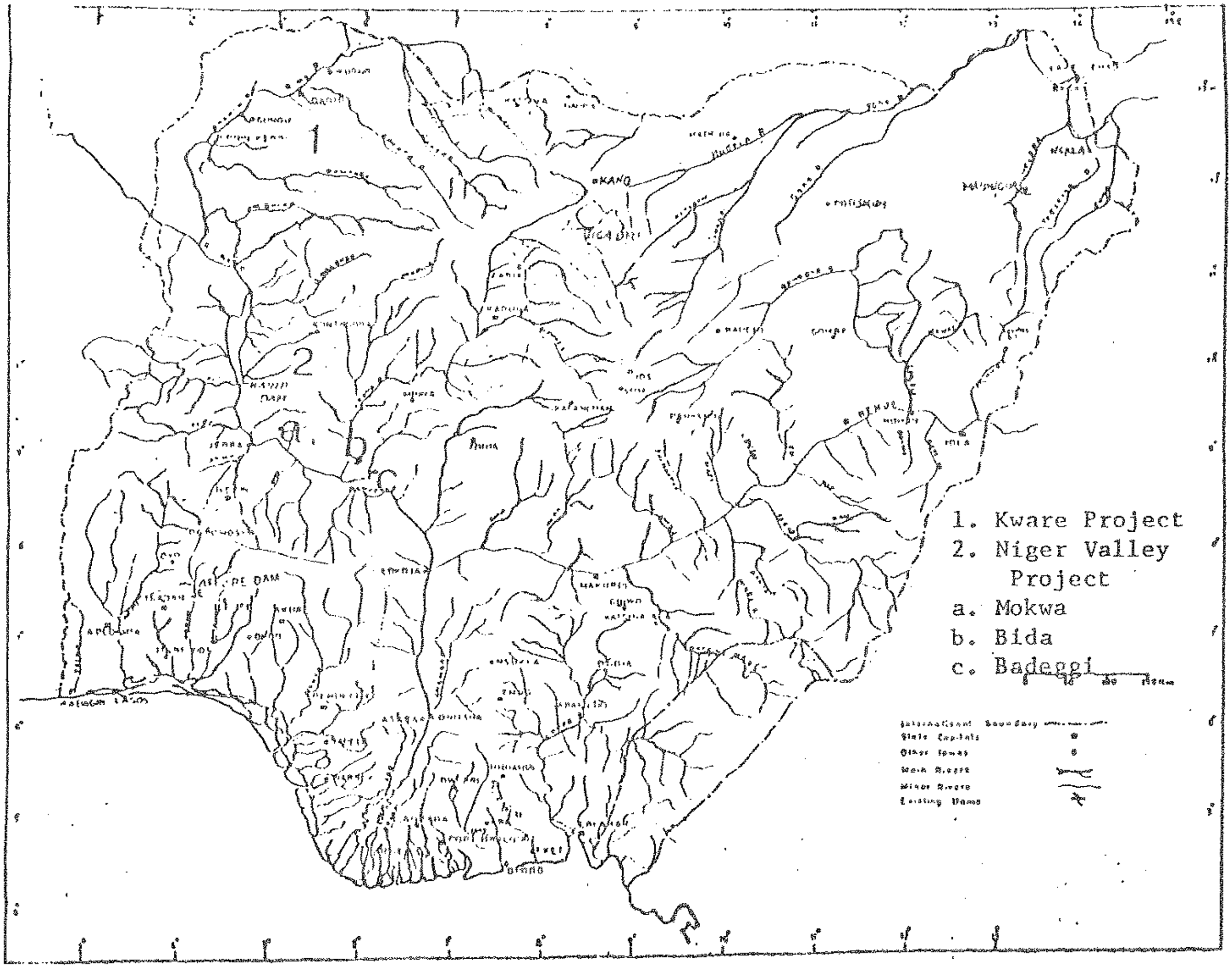


Figure 1.1. Surface Water Sources of Nigeria.

In 1949, the Irrigation Division was set up in the Northern Ministry of Agriculture, and attention was directed from the northwest (dry Savannah zone) to the middle belt (intermediate Savannah zone), resulting in the establishment of the Niger Valley Project at Mokwa (see Figures 1.1 and 1.2). Throughout the 1950s, the Division concentrated on small scale rice projects in the Niger Valley and some in Sokoto Province. During the same period a medium-sized rice scheme of 405 to 810 hectares was developed at Badeggi and Edozhighi. Between 1955 and 1960 about 500,000 pounds out of the total 1863 million pounds capital expenditure on agriculture in Northern Nigeria was allotted to these small scale irrigation schemes.

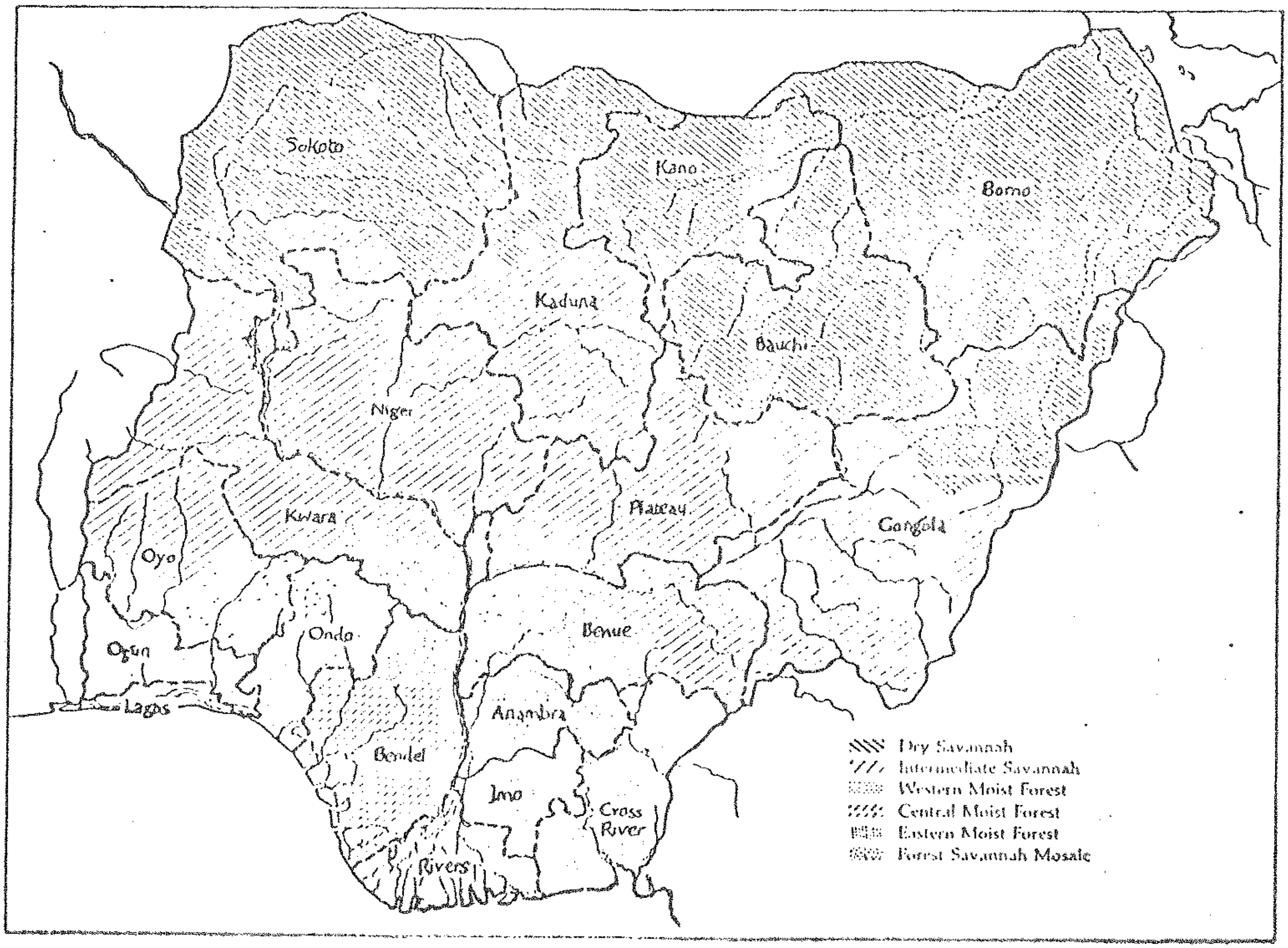
From 1956-65, the focus of irrigation development shifted from the Sokoto and Middle Belt provinces to small schemes. These include the Daya and Abadan, Gamboru, Kano, and Wurno projects which involved pumping from the Yobe, Ebeji, Hadejia and Rima Rivers, respectively. These schemes were all located in the dry or Sudan Savannah zone where wheat and rice were the crops grown. Together with a numer of other projects, they provided a significant increase in the area under organized irrigation as indicated in Table 1.2. Most of these projects are still operating at low levels of productivity. Others have disappeared from the record entirely, for example the Ja'agi project near Mokwa and Rabah [46].

During these irrigation development efforts by the Government, there were farmers who with the use of shadoof[1/] lift devices were irrigating small plots of vegetable crops, such as onion, pepper, and carrots. As reported by Olabanbosun (1974),

> "Irrigated cultivation was developed early in the North by the rural farmers as a result of unfavorable conditions of low rainfall and long periods of drought. Crops such as sugar cane, rice and various vegetables are grown on seasonally flooded riverine or fadama land in the vicinity of the citites of Kano, Zaria, Sokoto and Bida. The use of hand-scoops for watering the onion crops in the drier parts of Oyo and Ilorin represents a rudimentary form of irrigation. But a more improved method of shadoof irrigation is used in Kano and Zaria regions to water dry season crops--onions, carrots and other vegetable crops--for sale in the adjoining urban areas" [44].

The practices of the shadoof farmers were in most cases ignored by the Irrigation Division which favored large scale projection. Although the earlier projects were not altogether successful, they explored the water resources of the country and to some extent tested the potential for irrigation.

1/ Variously known as counter poise, Shadoof, Shadouf, dkenkali, Khetara, Kerkaz, Kheeraz, and guenina [33].



Source: Adapted from Idachaba, 1980 [28].

Figure 1.2. Ecological Zones and State Boundaries in Nigeria.

Table 1.2. Hectares under Irrigation by the Northern Provinces of Nigeria in 1961/62 and 1967/68.

Province[a]	Area under Irrigation	
	1961/62	1967/68
	----------hectares----------	
Borno	252	2303
Kano	77	423
Sokoto	40	441
Niger	992	1477
Ilorin	830	635
Plateau	0	46
Adamawa	0	18

a/ Details of area under irrigation by state and schemes were reported by Iqbal in 1975 [29] and earlier by Brown in 1962 [11].

Source: Adapted from Palmer-Jones, 1977 [46].

The Problem

The current drought in Northern Nigeria, the declining contribution of agriculture to the GDP, rapidly increasing food imports and the increasing need for agriculture to play a greater role in the socio-economic development of the country have further intensified interest in irrigation development [38]. The agricultural sector is expected to furnish the bulk of the nation's employment, provide for a more stable supply of better quantity food for an increasing population, and provide important raw materials for other industries. As a consequence, the major focus has been on possible remedial measures expected to stimulate agriculture, especially in arid areas of the North, where agriculture was previously presumed not possible [5]. Perhaps there has never been a time in the history of Nigeria when irrigation development has been given more favorable consideration by the government [6]. In the revised Third National Development Plan, provision was made for a total expenditure of 535 million naira[1/] on irrigation development. In 1978/79, 30 percent of the total agricultural budget went to irrigation. By the time that all of the irrigation projects have been fully implemented, total expenditures are expected to reach approximately 2 billion naira. Currently three large irrigation projects, i.e., the Lake Chad Basin Development, Kano River Project, and Sokoto Rima Basin Development--comprise the major part of irrigation development in Nigeria.

While the trend of irrigation development has been mainly directed towards large scale irrigation involving heavy capital investment (dams, resettlement, etc.) and land development, the small scale lift irrigation methods of applying water (e.g., shadoof and pump) though fairly well known and used by farmers in most arid and semi-arid regions of Nigeria, have been the subject of less consideration and discussion. This may have been partly due to relatively little or no research information concerning these lift devices. A more important reason may have been the assumption that only a few irrigation schemes requiring very high capital investment would lead to sufficient impact on agricultural production.

Regarding the weakness of the large scale projects Abalu and D'Silva (1980) state that

> "Even if the country could afford the heavy investment that would be involved, the tendency would be to create a landless class by displacing original owners of land and replacing them with fewer but more powerful and more wealthy individuals. In the absence of alternative employment opportunities, the result would be abject poverty in rural areas, as well as in urban areas which would experience heavy migration from the rural areas...It therefore becomes very important to concentrate

---

1/ One naira (N 1) equals about 1.65 dollars at current rates of exchange.

> on the social and human aspects as well as on the technical aspects of technological change" [2].

All too often, when production is low, the first approach to solving this problem is to employ a new technology which increases productivity without adequate consideration of the impact on farmers or the economy as a whole. Chambers (1979) reported that in many areas of the world people are treated as resources rather than users of resources, and as means rather than ends. Because of this, formulation of research priorities often start with a crop or a mechanical technology rather than with farmers and their interests. In contrast, this research is designed to study the small scale traditional irrigation farmers with the purpose of providing information that can help them use the productive resources at their disposal more efficiently, thus fostering the policy of increasing their well-being and food production in Nigeria.

A preliminary assessment of the northern states indicates the importance of the small scale traditional lift devices (with rivers, streams and wells as water sources) in agricultural production and dry season employment. The persistence of this traditional farming system throughout the irrigation development years is best summed up by the report of Norman (1972)

> "The farming system in the area reflects attempts by farmers to adapt to their environment over long periods of time. Because they have always been faced with low levels of farm resources, the level of technology they have come to prefer has been biased towards the low risk, low productivity traditional techniques that have been used by their ancestors for generations. There are, however, very sound reasons for the system of production they have come to adopt." [41]

There is, therefore, a need to investigate the potential production costs and to explore the cultural practices, cropping patterns, and the efficiency of resource usage associated with small scale irrigation. These small scale lift devices are relatively inexpensive, require little foreign investment and are capable of manufacture and operation with local resources and labor. Past and present irrigation development projects have lacked these advantages.

Objectives of This Study

In an attempt to provide the much needed information on resource use under small scale irrigation technology the following specific objectives have been identified.

1. To provide descriptive information about the capital and other resource requirements and the operating characteristics of small scale lift irrigation methods with particular reference to shadoof and pump.

2. To show the absolute and comparative impact of water availability, land, and other constraints on the costs and returns structure of small scale shadoof and pump lift irrigation systems.

3. To show the effect of varying the cost of pumping equipment and maintenance on the economic returns to shadoof and small scale pump irrigation.

4. To show the effect of uncertainty and risk associated with pump maintenance and repairs on yield.

5. To assess the implication of the above analysis with particular reference to research, extension, and government policy.

ANALYTICAL FRAMEWORK

The objective of this section is to present a broad conceptual framework within which the efficiency of resource use under small scale lift irrigation technology--shadoof and pump--can be analyzed.

Several models and analytical procedures of published nature have been designed to study the problem of small scale farms in developing countries [7, 8, 9, 10, 16, 22, 27, 34, 36, and 48]. However, they are not comparative in nature nor do they address efficiency of resource use under small scale irrigation technology. In addition, the methodology of these studies falls short in the analysis of intercropping (several crops intersown on the same field). The result has been reduced confidence in directly relating the amounts of variable inputs (land, labor, water, etc.) to production of a specific crop. This section therefore begins with a description of the Nigerian intercropping patterns and is followed by a review of recent procedures advanced by other researchers who have studied efficiency of resource usage. This review will cover a production function model [Cohen, 1975], linear programming using raw data [Hopkins, 1975], and linear programming using raw data including use of coefficients extrapolated from regression equation [Balcet and Chandler, 1981]. The final section of this chapter is a presentation of the methodology developed by the researcher to analyze input use by intercropping farms.

Intercropping

Intercropping involves the growing of two or more crops intersown in the same row, in alternate rows, or in clumps at various densities. This differs from multiple cropping which according to Dalrymple is "The practice of growing more than one crop on the same piece of land in a year. Multiple cropping makes possible both an increase in area cultivated per year as well as in total yield per unit of area per year" [17]. Although the arrangement of crops under intercropping varies virtually ad infinitum from individual producer to producer, from village to village, etc., it is possible to identify four broad patterns observed in plots using the basin irrigation method in this study area. These are the following:

(1) Interplanting within the same basin,

(2) Interplanting on the ridges of the basin,

(3) Interplanting in the furrows between basins,

(4) Interplanting in contiguous basins (small), i.e., each basin contains a separate crop.

Growing crops together in mixtures is a widely used traditional practice in the northern part of Nigeria [1]. However, progressive agriculture in developing countries and in the northern part of Nigeria in particular has been associated with sole cropping [42]. This fact apparently has not been convincing to the farmers, as reflected in Abalu's statement

> "Despite the alleged superiority of sole cropping to mixed cropping, and despite efforts by extension workers throughout the northern states of Nigeria to impress farmers with this superiority, there has been no apparent shift from crop mixtures to sole cropping" [1].

There are various rationales posited for intercropping practices. Norman (1970) suggests that in northern Nigeria growing crops in mixtures as (1) relatively more profitable than sole cropping and that there is no significant difference between the marginal value product of resource used and the opportunity cost of the resources, and (2) consistent with the goal of security [42]. Other possible reasons include risk avoidance [1], and balanced nutrition [3]. That intercropping is, in fact, superior to sole cropping has been further documented by several other researchers. Evans (1960) working in East Africa reported that "...intercropping is markedly superior to cropping in pure stands...there is an appreciable savings of land and labor" [20]. Norman (1970), on the basis of farm data from northern Nigeria states that "in general the average value of production for crops grown in mixture is higher than that of sole crops" [40]. Cohen (1981) in the research he carried out in Mali found that per hectare yield of millet in mixture is higher than in sole millet stands [14].

Some theoretical consideration has been given to farmers' behavior of intercropping. Herath (1980) advanced the theory of utility maximization as a suitable model to explain the adoption of mixed cropping--in the sense of partial adoption of high-yielding varieties--by rice farmers in Sri Lanka [24]. Balcet and Changler assessed farmers' behavior in northern Nigeria as being

> "essentially lexicographic, with the aim of self-sufficiency dominant, during the period spanning the start of the rain to the germination of the first food crops. If the rains are good this period typically ends at the first weeding; however if the rains are bad it can extend much later on into the season. After that critical stage the farmer gradually changes his objective from safety-first to income maximization and risk reduction as the season unfolds, and as he gains additional information on the prevailing state of nature" [9].

The need for mixed cropping may best be summed up by quotes from Burke (1980), and Balcet and Chandler (1981).

> "Results have shown clearly that the system (the mixed cropping, 'gicci' system) has irreplaceable benefits over sole cropping. In particular the value obtained from having a flexible sowing date-population strategy more than outweighs recommendation for a high plant population which requires a later fixed date sowing. The system has shown that over 40 percent greater income can be obtained compared with the respective sole crop and farmer has a greater element of choice in his strategy" [12].

> "One major point worth emphasizing is that traditional mixed cropping is seen to represent a sophisticated managerial reaction, used in the right circumstances, and it is cautioned that it should not be dismissed as being due to ignorance, or lack of knowledge" [9].

The above arguments suggest that intercropping is profitable, rational and will continue to be adopted by the farmers. Given the existence of intercropping the issue then is to find useful analytical procedures and tools to study the efficiency of resource use under intercropping and to find a means of directly relating the amounts of resources (land, water, labor, etc.) to production of specific crops within the system.

Review of Relevant Literature on Analytical Procedures

Models specified for the analysis of the efficiency of resource use are reviewed.

Production Function Model

Cohen (1981) specified a production function model to analyze resource availability and employment in the traditional cultivation systems of two villages in the Mopti region of Mali [14]. Production function analysis was used (1) to estimate the marginal returns to land and labor in cereals production as well as in specific mixed cropped enterprises, and (2) to analyze the economic interrelationships between millet and the component crops grown in mixtures with millet.

Based on Yotopoulos' (1967) three basic decision rules[1/] to choose among alternative functional forms [49], Cohen chose the Cobb-Douglas production function as the appropriate algebraic form to represent the production process.

$$Y = A_0 X_1^{b_1} X_2^{b_2}$$

where

Y = the total physical product (kg.) of millet and any component crops in mixtures with millet,

A_0 = a constant,

X_1 = hours of labor devoted to pre-harvest tasks,

X_2 = hectares of cultivated land in millet and any component crops in mixture with millet,

b_i = elasticities of production for labor and land to be estimated.

Two separate outputs (Y) were estimated based on two crop enterprises which he defined as (1) sole cropped millet and millet in mixture with roselle and/or cowpeas (referred to as millet), and (2) millet always in mixture with sorghum and in mixture variously with roselle and/or cowpeas (referred to as millet/sorghum). One of the basic criticisms of this model besides those associated with a Cobb-Douglas production

---

1/ The decision rules are: "(1) The production function presupposes a production process with a specific 'logic'. The functional form chosen should be consistent with the 'true' relationship. If the exact relationship is not known ex ante, which is often the case, the testing of an algebraic form with various criteria of statistical adequacy may, nevertheless, be a satisfactory means to approximate the 'true' function, (2) 'Given the body of established economic theory, the explicit relation chosen should offer possibilities of providing a unified explanation of a wide range of empirical phenomena, which would otherwise be given ad hoc interpretatons', and (3) It is desirable that the function display computational feasibility" [49].

function that he pointed out is "the number and type of crops in mixture with millet may alter the input-output relationship associated with different millet mixtures. Given the presence of these factors, it is unlikely that the factors of production will be used in constant proportion across all types of soil, plot size, and crop mixture." The use of total physical product of millet and component crops in mixtures create a further problem. Given that irrigated vegetable crops such as onion, peppers, tomatoes, garden eggs, carrots, spinach, etc. are grown, the weight of total physical product as output becomes misleading. Farmers having a greater proportion of onions, tomatoes, and garden eggs in the mixture will have by far a higher physical product than those with a higher proportion of spinach and peppers, even though the later proportion tends to be more revenue generating (higher prices per pound) and involves the same levels of input (land, labor, etc.). As Cohen stated, "The rarity with which one encounters sole cropped millet fields makes it difficult to compare the labor requirements, yields, and total revenue of these two cropping patterns." Assuming that five crops are grown in an area, then several combinations of two, three, four, and one combination of five are possible. If we define a combination as a crop enterprise (consistent with Cohen's definition), to obtain enough data to explore the resource use under the 20 enterprises possible is nearly impossible. There will not be enough observations available to analyze the majority of the possible combinations. Estimating an input-output relationship for these combinations within the same village will create yet another problem, because the marginal productivity of land in the production of an individual crop, e.g., peppers, cannot be estimated in the mixtures.

Linear Programming Model

Although linear programming is by no means a new technique in agricultural studies, Heyer (1971) has pointed out that "the large body of literature that now exists on the use of LP in farm production analysis includes remarkably little about small-scale farmers in developing countries" [20]. Given this premise, Hopkins (1975) used this methodology in order to test the hypothesis that LP is a useful tool for analyzing the behavior of semi-subsistence farmers. According to Hopkins

> "This method of analysis seemed particularly appropriate to a changing situation where new crops and techniques would not only affect farmers' incomes, but would also imply repercussions in the pattern of farming activities and resource allocations too complex to be analyzed by conventional budgeting or farm planning methods" [26].

To obtain the highly detailed data required for LP analysis, Hopkins used data collected from 26 case study households. From these she obtained the necessary information about the range of activities and constraints to be included in the model. She defined input and output coefficients and realistic levels of resource constraints for different farm types. Her model maximizes expected net cash returns subject to resource constraints and the satisfaction of a minimum food-stock requirement. In a modified version of the base model she investigated the effects of uncertainty in yield and prices using game theory concepts.

Her model neglects intercropping which she recognized as important and which is preferred by the farmers to pure stand methods they are expected to adopt in the agricultural extension scheme. She stated

> "If farmers are to be persuaded to abandon intercropping, therefore, there must be substantial arguments in favor of pure stands....It is true, of course, that planting in pure stands enables him to improve his techniques.... It is not clear that the increase in yields due to improved techniques will be sufficient to compensate for the loss inherent in passing from intercropping to pure stands" [26].

However, in her study, two-thirds of the cultivated plots in her sample were planted as pure stands. The reason she advanced for the neglect of intercropping was, "Because of the problem of defining planting densities and relating them to yield, we have not been able to include in our model the various crop mixtures which were observed." For those cases for which she considered input use under intercropping, it was in terms of a main crop. As she reported, "in some of our analysis of input data we have been able to use information from intersown plots, classified according to their main crop."

The attempt to analyze the issue of intercropping within a linear programming setting was undertaken by Balcet and Chandler (1981) and is summarized in the next section.

Obtaining LP Coefficients from Production Functions

Balcet and Chandler (1981) in their research which was designed to help understand and explain farmers' behavior regarding technology adoption in the World Bank's first three Agricultural Development Projects (ADP) in northern Nigeria at Funtua, Gusau and Gombe employed production functions and farm budgets to serve as a basis for constructing linear programming models [9]. The linear programming model was set up to deterministically maximize income subject to subsistence constraints in grains.

The production functions were devised to reflect the crucial interdependencies between crops in the mixed cropping system prevailing in the ADP areas, e.g., the yield of crops in mixtures was made dependent not only on inputs applied to the plot but also on the crucial characteristics of the other crops (planting density, crop management, etc.).

The use of a production function in an intercropping setting created problems which they explained as follows:

> "Estimation of technical production functions in a sole crop environment is relatively straightforward and well understood. There are only a few independent variables: seed variety, planting date, plant population, fertilizer treatment, harvesting date, together with any special husbandry practices. By contrast in mixed cropping, in addition to the above, one may have a multitude of other alternatives. There is also the question of the other crops included in the mix. Each crop may be planted in random fashion, in rows, etc. Rows may be planted on ridges, in furrows, or crisscrossing ridges; or individual plants may be planted in heaps....Furthermore, several crops may be combined with a continuum of relative intensities. The merits of most such alternatives have not been investigated even experimentally in most cases" [9].

In the face of the above problem, the authors hoped to obtain important information from survey data which could not be obtained from biological research at an acceptable cost within any reasonable period of time. They set out to estimate technical production functions employing two basic strategies. The first was to regard each crop mix as having its own separate production function, and hence to estimate yields as functions of inputs and husbandry practices used for that mix. The second was to focus on each crop as a dependent variable, and for the purpose of estimating the yield of this crop, to regard other crops in the mix as independent variables helping explain the yield of the particular crop being studied. In this way the data on all mixes involving, say, maize can legitimately be pooled, to help explain the yield of maize. Both strategies are akin to Cohen's production function estimations and as such are equally beset by the same difficulties enumerated under the previous description of his production function model. The results from the estimated equations show a relatively low coefficient of multiple determination, R^2, ranging from 15 to 30 percent, thus leaving 70 to 85 percent of the variation in the dependent variable unexplained. The authors suggested: (1) that despite the wide "net" thrown to collect agronomic factors, the most important causal effects have been missed and/or (2) that the yield data we are trying to explain contains a very large random element.

Despite the poor estimation result and problems associated with using conventional production function estimation for intercropping, the analytical procedure provided a means of obtaining coefficients for linear programming from production functions and budgets.

Methodology of this Study

To obtain the information necessary to accomplish the objectives of this study, 125 irrigation farmers in Ringim, LGA, Kano were interviewed each week during the 1978/79 irrigation season. Most of the farmers were middle-aged, had little formal education, owned multiple fields and planted a variety of crops. Of the 125 farmers interviewed, 114 used a shadoof lift system and 11 used motor driven pumps.

Technical and economic information on small irrigation technology was obtained from each of the 125 farmers. That information was analyzed with respect to resource use efficiency under small scale irrigation technology within the technical and resource limitations encountered in the survey.

Regression Procedure

The analysis specified in objectives 2 to 5 requires knowledge of the effect of variable inputs on the output. With different crop combinations grown on the farms (intercropping), it is difficult to directly relate factors, i.e., variable inputs (land, labor, water, etc.) used in production of a specific crop. The farmers of the study region irrigate four crops (garden eggs, onions, peppers, and tomatoes) in two or more crop combinations. Regression analysis offers one possibility of identifying the effect of the variable inputs on production of various crops. The factors can be regressed on the amount of the crop produced. Thus, input used in the production of a given output may be obtained. Thus

$$X = f(Y_1, Y_2, Y_3, Y_4)$$

where

X = units of input,

Y_1 to Y_4= units of output Y_1, Y_2, Y_3 and Y_4.

In the case of this study this regression of a single input on sets of outputs will be used to obtain coefficients for the variable inputs, i.e., land, labor and water. The labor was measured from October to December, January, February and March to May. Labor was used for land preparation (ploughing and clearing), planting, attending lift irrigation devices, opening channels, weeding and harvesting. The regression equations serve as a basis to construct small scale irrigation linear programming activities. The next section furnishes details of the linear programming model structure.

Model Structure

According to Heady (1971) there is a homogeneity in the agricultural planning environment among countries in that all farms have (1) plans or goals, (2) limited physical resources such as land, labor, buildings, machinery, capital, and water which restrain the range of plans or programs which are feasible, (3) institutional or subjective restraints which restrict the range of feasible plans considered or put into actual operation, (4) an objective function of some type to be maximized or goal to be approached, (5) weights which must exist to evaluate or express the contribution of alternative feasible plans toward objective function maximization or goal attainment, and (6) enterprises, technologies or activities which are competitive in the use of resources [23,4]. The model, therefore, is comprised of an objective function and a set of inequalities in which the right hand side represents a vector of resource supplies or other constraints. The left hand side of the inequalities contains technical coefficients of requirements for these resources multiplied by variables representing the levels of commodities to be produced. These inequalities define the technologies to be used, or the transactions to be conducted by the farm. The model is algebraically expressed as follows:

$$\text{Maximize} \sum_{j=1}^{n} C_j X_j$$

$$\sum_{j=1}^{n} A_{ij} X_j \leq b_i \qquad i = 1, 2, \ldots, m$$

$$X_j \geq 0$$

where

C_j is the return per unit of quantity j allocated,

X_j is the number of units of quantity j allocated,

A_{ik} is the use of resource i per unit of quantity j allocated,

b_i is the endowment of resource i.

Although this model structure and the implied principles of optimization are quite general,[1/] lack of appropriate data and problems of adapting universal planning models and principles to the specific farm environment hinder application. Consequently, the model used in this research was built using the farm data collected to get a whole farm[2/] view of the production process. This model is called the Production Possibilities-Convex Approximation Model (PP-CAM).[3/]

1/ The similarities include mathematical steps of computation, mathematical specification of optima, and specification of the economic or marginality conditions which define an optimal use of resource.

2/ More fashionably called "Farming Systems" [9].

3/ Production Possibility-Convex Approximation and PP-CAM will be used interchangeably throughout the discussion.

Objective Function and Resource Constraints Used

The objective function of the PP-CAM model involves maximization of expected net income subject to resource use constraints. This differs from the usual objective in subsistence farming which is to maximize expected net returns subject to meeting a minimum subsistence food requirements [9, 26]. However, in this study, irrigation farming which takes place during the dry season is strictly concerned with cash returns or personal income, while rainy season cropping provides the subsistence. Thus, the objective function is of the model used consistent with observed behavior.

The constraints are land, labor, and water resources. Other resources such as capital and fertilizer are not included in the model as constraints. This is reasonable because as the capital cost associated with the shadoof lift device is minimal since the farmers construct the system themselves. That associated with pump farmers will be treated as fixed cost. The production factors (land, labor, and water) considered are those common to both the pump and shadoof users, although the magnitude of use differs within and between the systems.

Production Possibilities of the Convex Approximation Model

The production possibilities convex approximation model specified for this research emphasizes the iso-product or product-product space which will be portrayed within a linear programming problem. In this study a group of inputs is used in the production of several outputs (garden eggs, onions, peppers, and tomatoes) simultaneously. To see this assume a function of the form

2.1 $X_i = f(G,P) \qquad X = 1, 2, \ldots, m$

where

G = garden egg in kilograms,

P = peppers in kilograms,

X_i = units of input i.

Then, choose a set of vectors, Y_1 to Y_m each of which is a plausible set of product ratios. One such vector would be three parts garden egg to one part pepper. Such vectors for two outputs are depicted in Figure 2.1. There is a vector through every point in the pepper-garden egg space. One then evaluates the input demand function (equation 2.1) at various points on the different vectors (Y_m) such as the point G3/P5 to obtain input combination X_m. This technique produces a series of output combinations and their corresponding inputs.

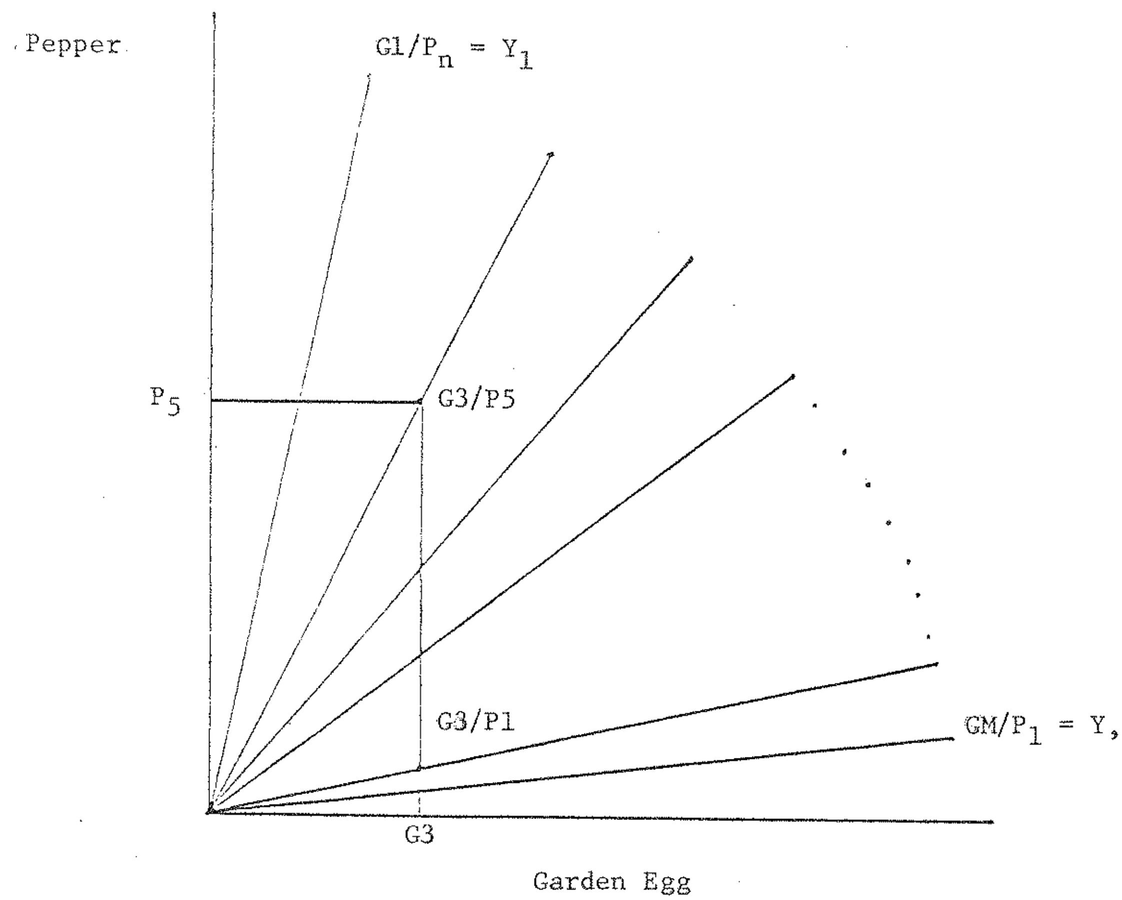


Figure 2.1. Product-Product Space Consisting of a Series of Product Ratios for Two Products (Garden Egg and Pepper).

To constrain the possible combinations and outcomes to those available in the region of the study, maximum and minimum outputs of each crop produced per hectare will be specified. In Figure 2.2a the horizontal line originating at P_1 is the minimum of pepper output per hectare and the line originating at P_2 represents the maximum of pepper output per hectare. The vertical line originating at G_1 is the minimum output per hectare of garden eggs and that at G_2 is the maximum output per hectare. To restrain the product ratios to conform with those used by the farmers, ray Y_{max}representing the maximum product ratio of garden egg/pepper and ray Y_{min} representing the minimum product ratio for garden eggs/pepper were derived from survey data. The shaded area ABCDE (Figure 2.2a) represents the set of permissible feasible plans. The rest of the product-product space denotes nonfeasbile values of products, the planning set alone is depicted in Figure 2.2b.

In this study to obtain an activity within the feasible plan three equal increments of each crop were chosen as represented by the four horizontal lines originating from P_1, P_2, P_3, P_4 and by the four vertical lines originating from G_1, G_2, G_3, G_4 for pepper and garden eggs, respectively, in Figure 2.3. Each line intersection represents a pepper and garden egg combination. This combination is defined as an activity. Of the 16 possible activities defined for two crops, 10 were considered feasible. The others were excluded from consideration because they were not observed in the survey. Each of the feasible output combinations, activity, is then substituted into equation 2.1 to obtain the input outcomes or coefficients required to produce that combination. In case of four crops the number of possible activities defined for three increments (Figure 2.3) or four points per crop is 256. The function (equation 2.1) is evaluated at the various feasible points Y_m, to obtain the inputs $X_1, X_2, \ldots, X_m$. Each of the Y-combinations in the feasible set including its associated X's then represent an activity column vector defined in the matrix of the linear program. The general linear programming model can then be represented algebraically as

i) Maximize $\sum_{j}^{4} C_j Y_j = \sum_{i} d_i Z_i$

ii) $Y_j = \sum_{m} Y_{jm\,m} \leq 0$

iii) $\sum_{m} X_{im} \lambda_m - Z_i \leq 0$

iv) $Z_i \leq b_i$

$Y_j, \;_m, Z_i \geq 0$

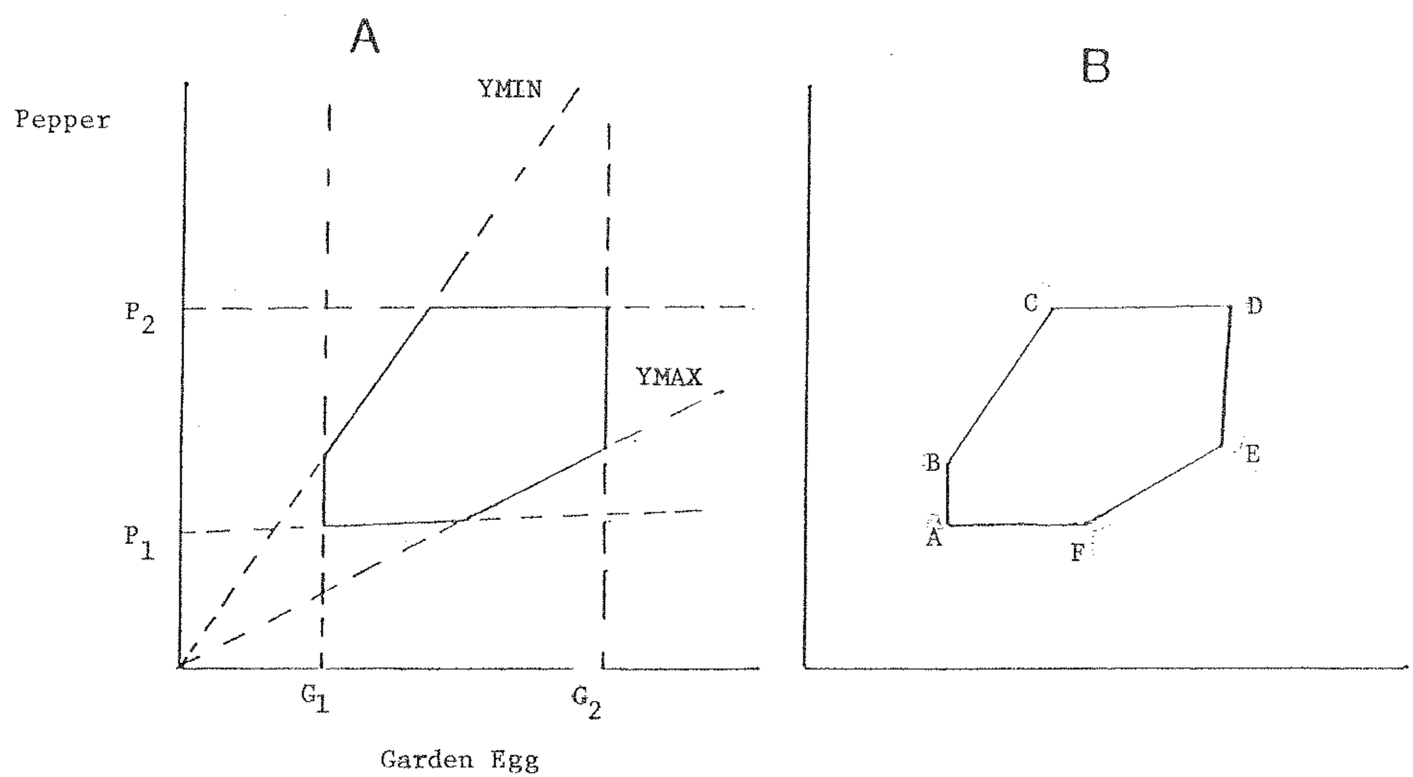


Figure 2.2. Feasible Planning Set with Garden Egg and Papper Minimum and Maximum Restraints.

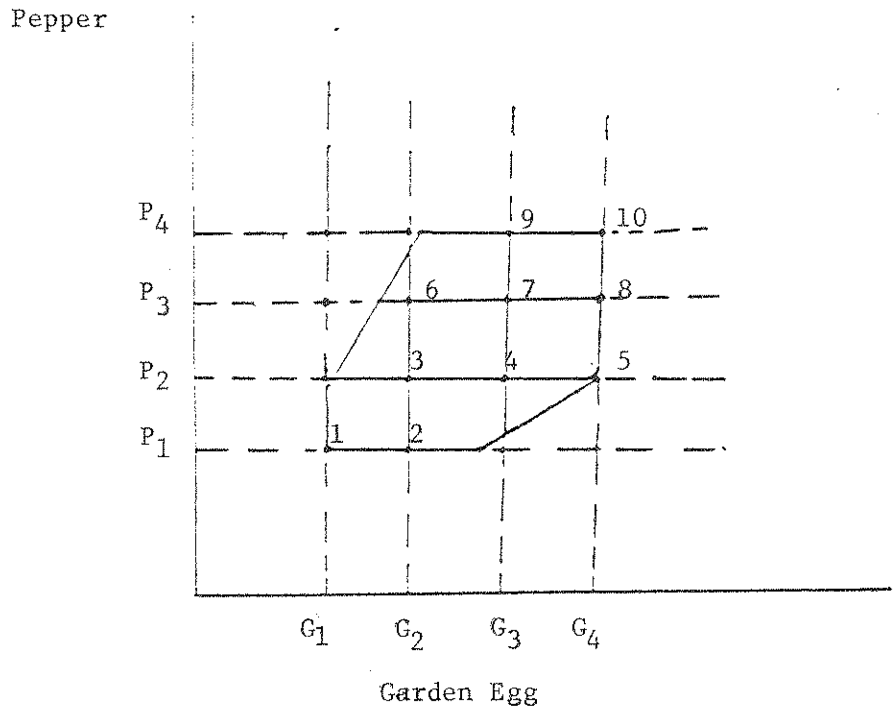


Figure 2.3. Output Combinations Defining Sets of Activities within the Feasible Plan.

where

C_j is the return or price per unit of the jth product,

Y_j is the total production of the jth product summed over all possible production processes,

d_i is the cost of the ith input,

Z_i is the total quantity of the ith input used in all production processes,

λ_m is the number of units of the mth production process employed,

X_{im} is the use of the ith input in one unit of the mth production,

b_i is the maximum availability of the ith input.

The schematic outline of the small scale irrigation (PP-CAM) linear programming model is presented in Figure 2.4. This model was used to study the efficiency of resource use under small scale irrigation technology within the confines of productivity in the area.

A computer program was designed to obtain the coefficients needed for this model from the empirical survey data. This program generated the coefficients in the input format which was accepted by the linear programming solver. A description of the study area and irrigation lift system data used and how it was obtained is presented in the next two major sections.

		Output Price											Hired Labor Wage Rate					
		G. egg	Onion	Pepper	Tomatoes	Y_1	Y_2	Y_3	Y_4	....	Y_m		Oct.-Dec	January	February	Mar.-May		
	Objective Fn.	+	+	+	+								−	−	−	−		Max.
	G. egg	+				−	−	−	−	....	−						$\leq$	0
	Onion		+			−	−	−	−	....	−						$\leq$	0
	Pepper			+		−	−	−	−	....	−						$\leq$	0
	Tomatoes				+	−	−	−	−	....	−						$\leq$	0
	Land = X_1					1	1	1	1	....	1	−					$\leq$	+
Monthly Labor Use	Oct.-Dec.					+	+	+	+	....	+	−	−				$\leq$	0
	January					+	+	+	+	....	+	−		−			$\leq$	0
	February					+	+	+	+	....	+	−			−		$\leq$	0
	Mar.-May					+	+	+	+	....	+					−	$\leq$	0
Labor Use by Activity	Clearing=X_2					+	+	+	+	....	+						$\geq$	0
	Plough=X_3					+	+	+	+	....	+						$\geq$	0
	Planting=X_4					+	+	+	+	....	+						$\geq$	0
	Lifting=X_5					+	+	+	+	....	+						$\geq$	0
	Opening=X_6					+	+	+	+	....	+						$\geq$	0
	Weeding=X_7					+	+	+	+	....	+						$\geq$	0
	Harvesting=X_8					+	+	+	+	....	+						$\geq$	0
	Family Labor											1					$\leq$	+
	Water Use					+	+	+	+	....	+						$\leq$	+

Y_1 to Y_m = various output combinations in the feasible set

Figure 2.4. Schematic Outline of Production Possibility-Convex Approximation (PP-CAM) Linear Programming Matrix.

DESCRIPTION OF THE STUDY AREA, DATA BASE, AND FEATURES OF IRRIGATION LIFT SYSTEM AND AGRICULTURAL INFRASTRUCTURES AS USED BY THE FARMERS

Preliminary Research Assessment

Prior to the intensive data gathering period (October 1978-May 1979) the researcher travelled extensively between July and September 1977 to six[1/] of the ten northern states of Nigeria to gain understanding and to quantify some aspect of the irrigation situation in Nigeria. A preliminary study questionnaire was used in this investigation.[2/] Four lift irrigation methods, shadoof, pump, bucket and calabash, and gravity or natural flow, were identified [18]. An estimated 43,600 farmers irrigate about 16000 hectares[3/] of vegetable crops with the four irrigaton methods as presented in Table 3.1.

Shadoof and pump are the major focus of this study. The other systems--bucket and gravitational flow are of minor importance to this study because they are "situational devices" which can neither be modified or improved upon. The bucket and calabash system was used mainly to irrigate seedling beds and supplement nursery water requirement. The gravity or natural flow system used predominantly in Sokoto and Niger States mainly involves the physical diversion of stream flow to the field by creating "home-made" dams.

Although the data collected in this survey is very sketchy, it was important in providing information on (1) the relative importance of shadoof, the predominant lift device, and (2) the importance of pump irrigation which by virtue of its newness is on a relatively small scale but may in time gain acceptance and popularity. Hence, the shadoof and pump were chosen for further study.

Based on the distribution of the hectares of shadoof and pump irrigation among the states (Table 3.1), Kono State best represents these lift irrigation devices. Fifty percent of the total irrigated hectares is under shadoof and 45 percent under pump. Within Kano State, Ringim Local Government Area, was identified as a possible study area for the following reasons:

1. Predominance of shadoof and pump which make up 24 and 83 percent of the irrigated area in Kano State, respectively.

1/ The states visited were Kano, Kaduna, Sokoto, Niger, Kawara and Benue. Bauchi, Plateau, Gongola and Borno States were not visited.

2/ The questionnaire was completed by agricultural officers and their assistants, irrigation engineers, and farmers.

3/ The figure on irrigated acreage seems higher than the reported figure of 14,569 hectares of irrigated land in Nigeria. However, the reported figure excluded the irrigated land along the fadamas which make up 141,643 hectares where lift devices are found.

Table 3.1. Summary of Hectares and Population Distribution by States in Northern Nigeria among the Different Irrigation Lift Devices in 1977.

State	Shadoof		Pump		Others		Total by State	
	Hectares	Population	Hectares	Population	Hectares	Population	Hectares	Population
Kano	2736	12110	1072	1730	--	--	3808	13840
Kaduna	1973	8280	726	920	1234	3620	3933	12820
Sokoto	579	2200	150	190	3448	7970	4177	2219
Kwara	109	480	45	169	1420	1570	1574	10360
Niger	51	165	249	352	2044	3375	2344	3892
Banue	--	--	125	428	4	25	129	453
Total (ha.)	5448	23235	2367	3789	8150	16560	15965	43584
Percent of States Total	34	53	15	9	51	38	100	100

Source: Erhabor, 1978 [18].

2. Central location.

3. Diverse water source including the Hadejia River Streams and wells.

The Study Area

Ringim LGA is located 110 kilometers northeast of Kano township. It is comprised of two districts, Garki and Ringim, with Ringim district practicing irrigated agriculture at Maje[1/] and Karwai Villages. These villages are located 46 kilometers northeast and 20 kilometers southwest of Ringim township, respectively. A map of the study area is presented in Figure 3.1.

Maje farmers use the pump and shadoof lift devices to irrigate larger areas than the Karwai farmers which employ only the shadoof lift devices. The topography is gently sloping with sandy loam and clay loam as the predominant soil types.

The climate is dry Sudan Savannah, characterized by 20 to 30 inches of precipitation during the rain season, May to September, and 95 to 110 degrees temperature during the dry season, October to May. In 1978, Ringim LGA recorded a total of 20.99 inches of rainfall, with 59 percent or 12.47 inches of the rainfall occurring in the month of August, traces of rainfall in May and less than 3.5 inches falling in each of the months of June, July and September. This low and highly variable annual rainfall occurring in a single rainy season is the dominant characteristic and one of the primary limiting factors for agricultural production in the region [30,31].

The first users of irrigation irrigated vegetable crops, sugar cane, okra and rice. At present, four major irrigated crops are garden eggs, onions, peppers and tomatoes. Of less importance, but gaining prominence, are wheat, carrots, spinach, and peas. The non-irrigated upland is cultivated only during the rainy season. It continues to be planted to the subsistence crops of millet, sorghum, cowpeas and roselle.

The water for irrigation has been lifted by shadoof and pump from rivers, streams and shallow wells to irrigate crops using basin flood irrigation methods. Maje farmers obtain their irrigation water from the Hadejia River and streams, with none of the farmers irrigating from wells. On the other hand, Karwai farmers irrigate from wells and the Hadejia River. These water sources are located two to five kilometers from the farming villages.

1/ Maje Village includes Gilma and Jangaci hamlets which are located 7 and 5 kilometers, respectively, from Maje Village.

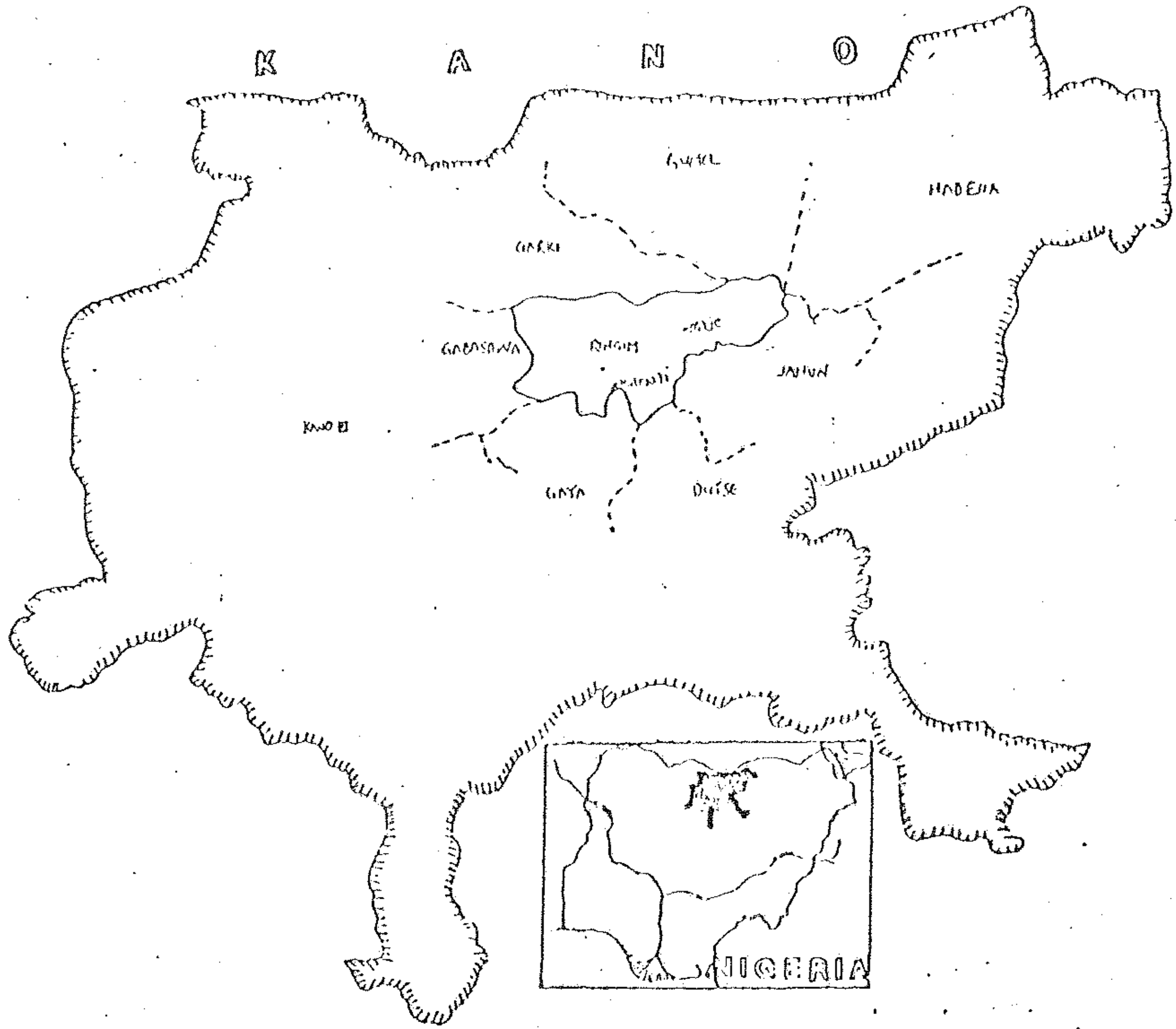


Figure 3.1. Maje and Karwai Villages, Ringim LGA, Kano, Nigeria.

Data Base

The entire population of 150 farmers using these irrigation devices (128 with shadoof and 22 with pumps) were interviewed. Not all the farmers interviewed irrigated during the 1978/79 irrigation season, the period in which this study was carried out. Fifty percent or 11 of the farmers using pumps dropped out of the study because of pump breakdown during the 1977/78 irrigation season. Eleven pump users remained in the study. Some who had used pumps changed from pump to shadoof and were included in that category of the study. Some of the shadoof farmers who expressed willingness to irrigate did not follow through. About 114 shadoof farmers were finally included in the study. This made a total of 125 farmers. Fifty of these farmers were from Maje and the other 75 from Karwai Village.

These farmers were interviewed weekly for 28 weeks between October 1978 and May 1979 by five enumerators each interviewing about 22 to 27 farmers. Due to the detailed in-depth data required by the study, the enumerators were stationed in the area for the duration and irrigation technology questionnaires were used on an intensive basis.

Hours and numbers of irrigation, inputs used and costs, hours of family and hired labor used and pay, non-farm activities other than farming that prevented or supplemented work in the field, and crop yield were recorded on the questionnaire. This set of data is presented, analyzed and transformed for use in PP-CAM model in the next major section.

Another set of data was collected on a single interview basis. The following types of information were recorded on the questionnaire:

1. Water supply including source, depth and how the farmer determines when to irrigate.

2. Lift device characteristics including design of device, and capital investment.

3. Preliminary data including education, number of children, number of children working on irrigated farm, number of acres in gandu (family farm) and gayauna (communal farm) and land tenure.

4. Policy or general questions including those addressed specifically to the pump farmers and shadoof farmers separately, about fertilizers and plant protection, crop, water, and land use, labor use, government and extension services.

5. Farm size.

6. Type of units for field measurements. Samples were taken of each unit weighted and recorded in kilograms in order to have standard measures for the different crops.

Characteristics of the Water Lift Devices and Irrigation Systems

Based on the single interview questionnaire, 114 of the 125 farmers interviewed used the shadoof lift system and 11 used motor driven pumps. Forty-two farmers operated two shadoofs on their farms but only one farmer operated two pumps. All of the other farmers irrigated with only one lift device.

Shadoof

The shadoof is a primitive lifting device which originated along the Nile and first recorded in tomb drawings at Thebes dating from 1250 B.C. It is one of the simplest and oldest devices for raising water by human power from streams, shallow wells and ponds. It is easy to construct, simple to maintain, and can be inexpensively replaced with locally available material. Generally the lift range of the shadoof is between one and three meters. When the lift from stream to fields exceeds this range it becomes necessary to use two or more of the devices in series [33]. The device is laborious to operate and lifts a limited amount of water per day. Hence, it is generally limited to irrigating small plots of land.

The technical specifications of shadoofs operated by the 114 farmers are presented in Table 3.2. The components of the shadoof consist of frame, pole, rod, counterweight, calabash, rope and wooden inlet. By pulling the rod down the operator lowers the calabash into the stream or well where it is filled with water. When the rod is released the counterweight lifts the calabash up from the water source to the level of the operator where he pours the water into a wooden inlet from which it flows onto the field.

The frame or support system is a Y-shaped tree branch of about five feet in length and four inches in diameter. The pole which is laid across this crutch frame is about 23 feet long and five to six inches in diameter. The length of the pole varies from 13 to 35 feet, depending on the distance the field is from the water source. The counterweight of stone or mud which is attached to the lower end of the pole ranges from 9.01 to 54.50 kilograms. The rod connected or attached to the upper end of the pole is about 12 feet long and two inches in diameter. The length of the rod varies from five to 22 feet, depending on the height of the device from the water surface. The calabash is hemispherical and varies in size from 1.5 to five gallons with two gallons (8 liters) the most common. The rope which connects the calabash to the rod allows for flexibility. It varies in length from six inches to eight feet with 12 inches most common. The wooden inlet ranges in length from six to 16 feet with 10 feet most common. The inlet empties into the primary canal, and reduces seepage and time lag before the water begins to flow into the field.

A typical operation (see Table 3.3) involves two operators. One person lifts water with the shadoof to a height of about eight feet and the other person distributes the water in the field by opening and closing the channels between rows. Each farm is irrigated twice a week

Table 3.2. Component Specification of Shadoofs of 114 Farmers in Ringim LGA, Kano, Nigeria During the 1978/79 Irrigation Season.

Component	Length		Width		Size	
	Average (ft.)	Range (ft.)	Average (in.)	Range (in.)	Average	Range
Frame	5	3-6	4	3-9	--	--
Pole	23	15-35	6	4-9	--	--
Rod	12	5-22	2	1.5-4	--	--
Counterweight	--	--	--	--	36.04 kg.	9.01-54.5 kg.
Rope	1	5-8	1	.5-2	--	--
Wooden Inlet	10	6-16	--	--	--	--
Calabash	--	--	--	--	2 gal.	1-5 gal.

Table 3.3. Irrigation Procedures Used by 114 Farmers Irrigated with Shadoofs in Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Item	Average	Range
Number of operators per irrigation	2	2–4
Number of people lifting water	1	1–2
Number of people distributing water	1	—
Number of irrigations per week	2	1–4
Number of hours per irrigation	4	1–7
Height of device from water (feet)	8	4–15
Depth of water source (feet)	5.5	1.5–13
Time to construct	3 days	3 hrs.– 9 days
Irrigated hectares	.1582	.029 to .614
Type of crops grown	onion, pepper, garden egg, and tomato	

with each application lasting about four hours. The water sources for the shadoof farmers are wells or rivers with a water depth ranging from 1.5 to 13 feet. The volume of water lifted depends on the height lifted, size of calabash, and number of men working. An earlier study in the Zaria area of Nigeria reported an average of 10 buckets or calabashes lifted per minute [40]. Since the average calabash size is two gallons, the estimated average water discharge is 20 gallons per minute or 1200 gallons per hour (4,542 liters per hour).

The farmers using the device reported growing between two and eight crops on their farms with three crops most common. The main crops grown are onions, peppers,garden eggs and tomatoes, with wheat, okra, spinach and tobacco in smaller quantities. The field sizes under shadoof range from .029 to .614 hectares with 0.158 hectares as the average field size.

Motor Driven Pump

The pump lift device utilizes a rapidly rotating impeller to raise water from a supply source to a higher level. The casing in which this high speed rotor is enclosed is so designed as to direct the water through and away from the impeller. The centrifugal type of impeller is the most widely used for irrigation pumping. It is relatively simple in construction and can be adapted to a variety of conditions. The common brands of centrifugal pump available in Nigeria are the Honda and Lister.

The pump was first introduced to the farmers in Nigeria by agricultural instructors and friends of the farmers in the early 1970's. Pumps have been owned by farmers in the area for one to four years. The farmers used their personal savings to finance the purchase of the pumps. About 58 perqent of the farmers were unaware of the availability of a 30 to 50 percent government subsidy on pumps purchased for irrigation. The 42 percent of the farmers aware of this subsidy made little or no effort to collect the subsidy due to the bureaucratic difficulty in obtaining it. That pumps in general are not easily available was indicated by the fact that 73 percent of the farmers encountered great difficulty in buying a pump from a private firm.

The pump is an imported device which the farmers purchase in Kano from the UTC and Leventis companies. Specific characteristics of pump as reported by 11 farmers are presented in Table 3.4. The pumps are three horsepower in size with water output of about 198 gallons per minute or 750 liters/minute. Nine farmers reported using the Honda type and two farmers used the Lister type. The efficiency of the pumps depends on the fuel type--petrol or diesel---that is used. The diesel model pump has a 90-100 percent water delivery efficiency and the petrol model pump is 70-80 percent efficient. The diesel model requires less maintenance and has a longer useful life. Although these operating advantages exist for the diesel model, all the farmers owned the petrol model pump because it is much cheaper to purchase than the diesel model.

Table 3.4. Characteristics of Pumps and Irrigation Procedures of 11 Farmers in Ringim LGA, Kano, Nigeria in 1978/79 Irrigation Season.

Item	Typical Farm Characteristics	Farmer Users	
		No.	Percent
Type of pump	Honda	9	82
	Lister	2	18
Energy or fuel type	Petrol	11	100
Number of irrigations/week	2	10	91
	3	1	9
Number of hours/irrigation			
Average	4 hours	--	
Range	3-6 hours	--	
Number of crops grown	3 crops (onions, peppers, and garden eggs)	8	73
	4 crops (onions, peppers, garden eggs, and tomatoes)	3	27
Water Source	River	11	100
Irrigated hectares			
Average	.8142	--	
Range	.129-1.413		
Problems with Pump	Stops frequently	3	27
	Oil leaking	1	9
	Crank shaft or piston	2	18
	None	3	27

The water source used by the pump farmers is the river. The water supply is seasonal and the farmer determines when to irrigate by past experience and observation. Ten farmers reported irrigating their land twice a week and one farmer reported three times a week. The hours per irrigation application vary from three to six hours with four hours reported by five of the farmers. Eight of the farmers planted a combination of three crops, i.e., onions, peppers, and garden eggs, and two farmers reported four crops, i.e., onions, peppers, garden eggs, and tomatoes. The field sizes range from 0.129 to 1.413 hectares with .8142 hectares as the average field size.

All but one of the pump farmers had problems with the device. Major problems reported by the farmers include the pump stopping frequently, oil leakage and the crank shaft or piston malfunctioning. Seven of the farmers experienced these problems during the first year of purchase. Other problems encountered with the pump included lack of spare parts and a long distance to the servicing station (156 kilometers). In cases of pump breakdown during the cropping season, about 58 percent of the farmers took the pump for service, waited until it was serviced, and then returned home with it. Only one of the farmers reported using a shadoof as an alternative water lift system pending repairs. All the pump farmers had used shadoof lift devices prior to purchasing a pump. Two major reasons advanced by the farmers for changing to pump irrigation were the use of less labor and ease of operation. Other reasons indicated were a higher crop yield and the ability to finance the purchase.

External Situational Factors Influencing Expansion or Adoption

During the survey, particular attention was given to the factors that farmers felt affected their ability to expand the irrigation operations to additional hectares or to adopt the pump irrigation lift device. This section presents the initial response of the farmers and then explores each of the factors in more detail.

The farmers were asked to rank in order of importance their major irrigation problems (Table 3.5). Pump farmers indicated that barriers to irrigation farming were more critical than did shadoof farmers in all problem areas except one. Based on a rank scale of 1 (very important) to 4 (not important), both the pump and shadoof farmers ranked water availability as the most important decision variable influencing the expansion of irrigation technology. While the pump farmers ranked labor as a very important decision variable, the shadoof farmers ranked it at a lower level because they felt they had an adequate supply of family labor. In order of importance the pump farmers ranked capital and fertilizer as second, pump servicing and seed as third, and the extension service as fourth. The shadoof farmers ranked capital as second, seed and pump servicing as third and fourth, respectively, and fertilizer and the extension service as fifth and sixth, respectively. Most of the farmers ranked the disease problem as not important.

Table 3.5. Ranking of Major Problems Hindering Irrigation Farming as Reported by 115 Farmers in Ringim Local Government Area, Kano, Nigeria, during the 1978/79 Irrigation Season.

Problem	Pump Farmers		Shadoof Farmers	
	Average Rank[a]	Order of Importance	Average Rank[a]	Order of Importance
Disease	4.000	5	3.233	8
Seed	1.182	3	1.427	3
Labor	1.000	1	2.245	7
Capital	1.091	2	1.343	2
Fertilizer	1.091	2	1.689	5
Pump Service	1.182	3		
Extension Service	1.384	4	1.900	6
Water Availability	1.000	1	1.152	1

[a] Rank was classified into: 1 = very important, 2 = important, 3 = less important and 4 = not important.

Land and Water Resources

In most developing nations land and labor are the two most important inputs in traditional agriculture. All the pump farmers and 85 percent of the shadoof farmers reported owning their land. Most of the irrigated land is located in the low land along the river bed. Upland farmland which constitutes 85 percent of other land owned by the farmers is not generally irrigated during the dry season. However, when irrigated, the upland soils can be used for vegetable crops found under irrigation during the dry season in the bottom land. During the rainy season the same crops are grown in both locations with subsistence crops such as millet and sorghum most common. Results of soil sample analysis conducted by the Soil and Water Laboratory in Kano indicated the soil is relatively fertile with ample amounts of the chemical nutrients required for plant growth [47].

Those few shadoof farmers who irrigate the upland use shallow wells as their water source. The reasons most farmers did not irrigate upland areas involved the distance from water supplies or the availability of water supplies. About one-half of the pump farmers and one-third of the shadoof farmers reported that the water supply for irrigation has not been continuously available during the past four irrigation seasons. If farmers could depend upon an adequate source of water for irrigation, they indicated they would expand irrigated area by six hectares and two hectares for the pump and shadoof systems, respectively. Although it would be extremely difficult for farmers to expand their area by the 700-1000 percent indicated, their positive response indicates land is not viewed as a constraint, but the water supply is a serious barrier to irrigating more land.

Labor and Credit

Mellor (1967) has pointed out that production in traditional agriculture may be limited by the amount of labor provided by the farmer, directly for production and indirectly through the formation of capital [32]. There are four kinds of labor used in Nigeria, i.e., family labor, communal labor locally called Gaya, contract labor known as Jinga, and daily paid labor known as Kawdogo. All farmers with pumps and 66 percent of the shadoof farmers reported having ready access to hired labor for irrigation. The shadoof farmers who did not have access to hired labor did not find labor a limiting factor because they had an adequate supply of family labor. The average wage paid for labor varied from 50K1/ to N2.00 per day.

Credit facilities were not available for the farmers. Capital or credit availability is a crucial variable in the adoption of the pump water lift device, but is less important to shadoof farmers who make

1/ One hundred kobo (K) equals one Naira.

their lift device from local materials. Nearly all the shadoof farmers reported the high investment cost of a pump as the factor which limited their adoption of the device even though 73 percent of the farmers preferred the pump to the shadoof. Limited capital or credit is a further constraint to major expansion of irrigated area because cash is required to purchase other farming inputs, e.g., fertilizer and seeds, needed for the realization of the high yields potentially available with irrigated farming.

Fertilizer and Chemicals

Most farmers in the area used fertilizer on their farms. During the four seasons, 1974/75 to 1977/78, all farmers with pumps and 80 percent of the shadoof farmers reported using fertilizer. About 76 percent and 100 percent of the shadoof and pump farmers, respectively, reported buying fertilizer at the government fertilizer depot in Ringim township. The remaining 24 percent of the shadoof farmers buy fertilizer from Kano or other villages. Fertilizer bought from the depot is heavily subsidized by the government, so the farmers pay only about 20 percent of the market price. Although the average price of fertilizer paid by the farmers has been declining each season, there is a great deal of variability in the price paid by individual farmers because some shadoof farmers pay market price rather than government subsidized prices. Fertilizer does not appear to be a constraint on further irrigation development because it is readily available, currently used by farmers, and priced at a very low subsidized level which makes it an attractive investment.

Plant protection chemicals such as herbicide and insecticide are not popular among the farmers in the area. This situation exists even though the yield of garden eggs and peppers is severely affected by virus. Although 64 percent of the pump farmers and 55 percent of the shadoof farmers knew about plant protection chemicals, only 64 percent of the pump farmers and 14 percent of shadoof farmers had ever used any form of crop protection chemical. Of those using crop protection chemicals, most get the quantity required whenever needed during the season. The use of crop protection chemicals was demonstrated to the farmers with pumps by an agricultural instructor and to the shadoof farmers by farmer friends. If there are any disease problems particularly associated with irrigation, this lack of chemical protection could inhibit irrigation expansion, but it would have little influence on the type of irrigation lift device used by the farmers.

Seeds

All the farmers with pumps and 53 percent of shadoof farmers reported they could obtain the quantity of seed (local variety seed) they need from their own farm or the village market within a few days. Improved seed is not readily available.

Personal Factors

Age and education bore no perceptible relationship to adoption of pump vs. shadoof water lift devices since most farmers using irrigation were middle aged (average of 40 years for shadoof farmers and 42 years for the pump farmers), and only 10 percent of the farmers interviewed had any Koranic or Arabic education. Most of the pump farmers irrigate for market sales while the shadoof farmers are more oriented towards subsistence farming. The farmers in the area are more experienced in the use of the shadoof lift device than the pump which is a more recent innovation. Water management is very rudimentary with most of the farmers determining when to irrigate by using subjective evaluations from their past experience. The farmers are not familiar with any technical water management principles.

Location

The location of a particular village greatly affects the expansion of irrigation or of pump technology. Poor roads, limited means of transportation, and small markets greatly affect the availabilities and cost of supplies of most farm inputs, and the marketing of the harvested crops. About 70 percent of the shadoof farmers reported lack of transportation as a major marketing problem. The location also makes it difficult for the pump farmers to have pumps serviced when the nearest servicing station is about 156 kilometers away.

The Role of Government and Extension Service

The role of the government and extension personnel is to encourage improved farming activities, and to provide information that the farmers need. About 99 percent of the farmers interviewed reported that no special program on irrigation has been presented in the area by the government. Only four pump farmers have received any advice on irrigation practices from the government. The only pump use demonstration took place more than five years ago and no government personnel have visited since the demonstration. Not only has little information about lift devices been provided to the farmers, but neither has information on irrigated crop production practices or water source development has been provided by the extension service personnel. None of the farmers were provided farm credit to develop their irrigation farming operations. Farmers' organizations such as marketing institutions, credit institutions, and farmers' clubs are virtually nonexistent in the area.

The government, through its agencies, is supposed to make material inputs available to the farmers. Government fertilizer services have been adequately provided and the majority of the farmers obtained fertilizer from Ringim Township. Very few of the farmers have access to improved seed because it is not made available by the government agent responsible for its distribution. The government has failed to provide easily available credit to buy a pump or service for pumps purchased by the farmers. In many cases the spare parts necessary for the maintenance of the pump are not available. The government has to a limited extent addressed the issue of water supply by the construction of Tiga Dam upstream from the Ringim LGA to control and regulate water supply. This has been helpful in reducing some of the fluctuation of water available to the farmers for irrigation. However, government programs have not addressed that issue of providing irrigation water for upland farms.

The lack of credit, an adequate water supply, extension service, pumps and/or spare parts greatly reduces the capacity of farmers to expand the area irrigated and to adopt pump lift devices. More efficient execution of the government's policies with respect to these items could increase irrigation and achieve higher levels of food production.

DATA ANALYSIS

A brief account of the data collected by weekly interviews and detailed discussion of the analysis required to extract information necessary for the model are taken up in this chapter. Information from 125 farmers was recorded weekly throughout an agricultural season, from the last week of October 1978 to the first week of May 1979. The data collected from 114 of the 125 farmers were usable. Reasons for excluding 11 farmers include: (1) farmers sold their fields and withdraw from irrigated farming as the season progressed, and (2) serious omissions in the data recorded. Of the 114 farmers, 104 used a shadoof lift system and 10 used motor driven pumps. To facilitate the analysis, the data were coded to reflect the different operations carried out on the farm.

Yield and Prices

The yield data were coded according to the crops grown--garden eggs, onions, peppers, tomatoes and other crops (wheat, roselle and okra). The data recorded under each crop include the purpose of the harvest (sale, home consumption, etc.), type of units (basket, sacks, etc.), number of units, price and total value as shown in Table 4.1.

Twenty-nine of the 114 farmers reported harvesting portions of their crops for home consumption. These 29 farmers were characteristically shadoof farmers irrigating very small areas of land in Karwai village. About 45 percent or 51 farmers reported using some of their harvest as gifts. However, 95 to 99 percent of the quantity of the crops harvested was sold either on the farm or in the market places located in the villages.

The type of units of measurement are numerous and of different sizes, shapes and weights depending upon the crop. The seven types of units identified as used by the farmers were kerosene tin, large basket, small basket, bucket/calabash, Mangala, Chali or Cali, bag/ sack. While all the seven units were reportedly used by the farmers as measures for garden eggs, onions, and peppers, only the small basket, bucket/calabash and sack/bag were used as measures for tomatoes. About 5 to 15 samples of

Table 4.1. An Example of Farm Data Record, Ringim LGA, Kano, Nigeria, during the 1978/79 Irrigation Season.

Description	Answers	Code	Column
Crop 2 Onions (17)			
Purpose of harvest	Home consumption	1	
	Sold	2	22
	Gift	3	
	Other (storage)	4	
Type of Unit	Kerosene tin	1	
	Basket (large)	2	
	Basket (small)	3	
	Bucket	4	23
	Mangala	5	
	Chali	6	
	Sack	7	
	The whole field	8	
No. of Units	Actual	Actual	24-26
Unit Price	Naira x 100	F4.2	
	e.g. 1.50 x 100 = 100		
	13.00 x 100 - 1300	actual	27-30
Total Value	Naira x 100	F5.2	
	e.g. N9.50 = 9.50	actual	31-35
	N416.00 - 41600		

each unit filled with each crop were weighed. Weights were recorded in kilograms. The average weights obtained in this process are presented in Table 4.2.

The averages in Table 4.2 were used to convert the data reported by the farmers into total kilograms of the crops grown on the farm. Besides the weekly recording of the yield data during the season, at the end of the season the farmers were interviewed about the amount of the crops harvested from the farm. This data was converted into total kilograms of each crop and the result compared with that obtained from the weekly interviews.

These yields in kilograms form the base data from which the yield coefficients for the model were computed. The total kilograms of each crop per hectare was calculated for each farm. The maximum and minimum of the yield per hectare and product ratios obtained is shown in Table 4.3. This result defines the feasible planning set in the study area. The yield coefficients for the PP-CAM model were obtained using the results in Table 4.3 and following the procedure outline under the model structure section of Chapter II. The estimated yield coefficients were normalized on one hectare of land.

The price per kilogram of each crop for the different units of measurement used by the farmer is presented in Table 4.4. The average price of garden eggs was 9 Kobo per kilogram (9K/kg.); onion, 16K/kg.; peppers, 30K/kg.; and tomatoes, 13K/kg. These prices were used in the objective function of the model to maximize expected net income, i.e., total revenue minus total cost of hired labor.

Land

The land area farmed was obtained by measuring and mapping the fields.[1/] An example diagram on a land measurement form is presented in Figure 4.1. The instruments used in the field measurement included measuring wheels, ranging poles, tape measure, and angle finder. A total of about 26 hectares was farmed by the 114 farmers with usable data. Thirty-two percent of the land (8 hectares) was farmed by those using motor driven pumps and the remaining (18 hectares) by farmers with shadoof lift devices (Table 4.5). The field sizes under shadoof ranged from 0.029 to 0.614 hectare with 0.1709 hectare as the average field size. The field sizes under pump range from 0.129 to 1.413 hectares with 0.8342 hectare as the average field size. The average field size for all the farmers reporting was 0.2291 hectare.

1/ Adapted by this study for the field measurement was "the guide to the principles and techniques of field measurement" written by Onwuchekwe for the Dept. of Agricultural Economics and Rural Sociology, IAR/ABU, Zaria

Table 4.2. Conversion[1/] of the Farmers' Measurement Units to Kilograms in Ringim LGA, Kano, Nigeria, during the 1978/79 Irrigation Season.

Unit of Measure	Average Conversion to Kilogram by Crops			
	Garden Egg	Onion	Pepper	Tomato
	(kg.)			
Kerosene Tin	18	20	16	
Basket (Large)	31	36	29	
Basket (Small)	10	9	10	15
Bucket/Calabash	16	14	14	17
Mangala	74	86	45	
Chali	71	84	43	
Sack/Bag	53	96	51	36

1/ Each conversion factor is based on a sample of 5 to 15 observations.

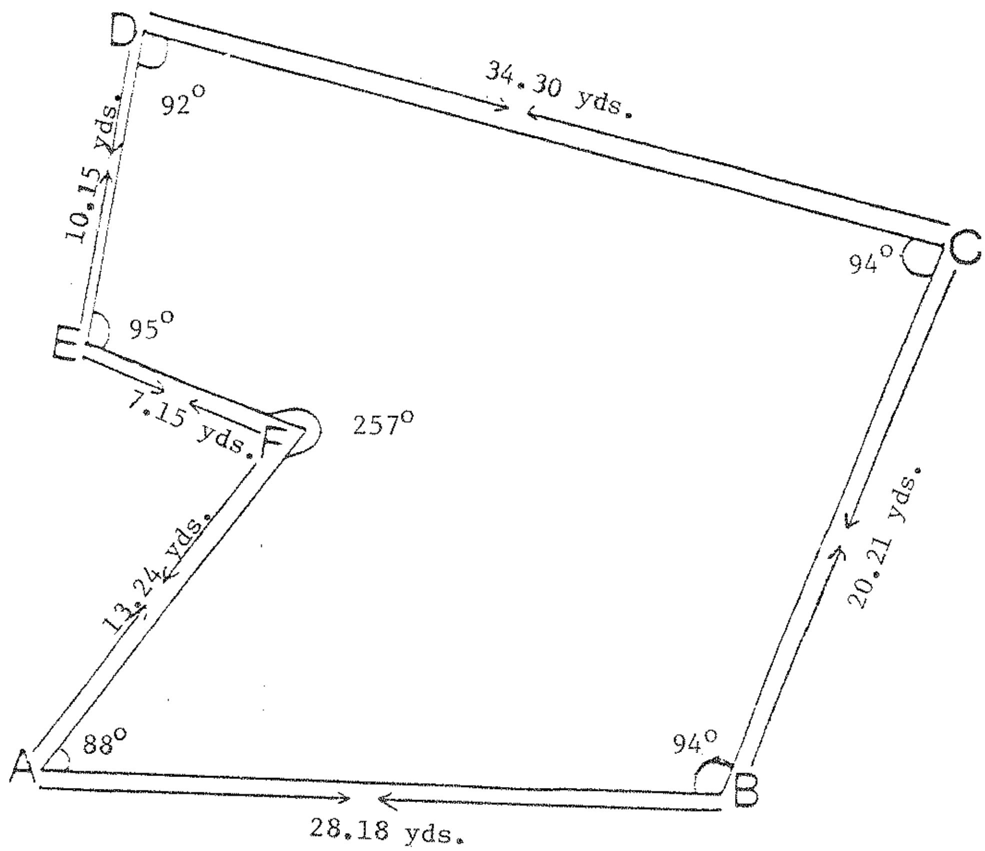
Table 4.3. The Minimum and Maximum of the Yields per Hectare and Product Ratios for Farms in Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Product or Ratio	Minimum	Maximum
1. Garden Egg (kg/ha)	630.952	22945.736
2. Onion (kg/ha)	781.818	26393.443
3. Pepper (kg/ha)	37.736	34090.909
4. Tomatoes (kg/ha)	45.317	3156.917
Onion/garden egg ratio	.058	9.081
Pepper/garden egg ratio	.020	9.189
Tomato/garden egg ratio	.004	.642
Pepper/onion ratio	.006	13.081
Tomato/onion ratio	.008	1.063
Tomato/pepper ratio	.004	3.534

Table 4.4. The Price of Garden Eggs, Onions, Peppers, and Tomatoes Grown in Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Unit of Measure Used by the Farmer	Garden Egg		Onion		Pepper		Tomato	
	Valid Cases (No.)	Price per kg. (Kobo)[a]	Valid Cases (No.)	Price per kg. (Kobo)	Valid Cases (No.)	Price per kg. (Kobo)	Valid Cases (No.)	Price per kg. (Kobo)
Kerosene Tin	3	28	8	32	4	22		
Basket (large)	47	9	9	12	25	24		
Basket (small)	189	13	107	29	56	30	6	11
Bucket/calabash	149	4	22	27	17	23	16	9
Mangala	93	8	170	10	6	18		
Chali	83	6	131	10	9	16		
Sack/bag	20	11	38	12	169	33	3	36
Ave. Price/kg.	9		16		30		13	

[a] 100 Kobo = 1 naira



Size = 0.076 ha.

Crops found on field
1. Onions
2. Peppers
3. Garden Eggs[a/]
4. Tomatoes

Figure 4.1. Farm Size and Crops Found on a Sample Farm.

a/ Garden egg is a variety of egg plant. However, it is smaller than the variety common in the United States and whitish in color.

Table 4.5. Areas Irrigated by 114 Farmers Using Shadoof and Pump Irrigation in Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Lift Devices	No. of Cases	Area Irrigated				
		Total		Minimum	Maximum	Average
		(ha.)	(%)	(ha.)	(ha.)	(ha.)
Shadoof farms	104	17.776	68	0.029	0.614	0.1709
Pump farms	10	8.342	32	0.129	1.413	0.8342
All farms	114	26.118	100	0.029	1.413	0.2291

CURRENCY EQUIVALENTS

Currency Unit	=	Naira (₦)
US$1	=	Naira .606
₦	=	US$1.65

WEIGHTS AND MEASURES

Unless otherwise stated, all weights and measures used in this report are metric:

1 metric ton	=	0.98
1 hectare (ha)	=	2.47 acre
1 kilometer (km)	=	0.62 mile
1 kilogram (kg)	=	2.2 pounds

In order to obtain land coefficients for the model, the field size was regressed on the production of garden eggs, onions, peppers, and tomatoes. The equation for estimating land use is

$$4.1. \quad \underset{(3.64)^{**}}{X = 0.0631} - \underset{(-1.08)}{.0000195\, Y_1} + \underset{(4.96)^{**}}{.000072\, Y_2} + \underset{(7.87)^{**}}{.000101\, Y_3} + \underset{(4)^{**}}{.000164\, Y_4}$$

$R^2 = .74$ F-statistic = 78.4 n = 114

where

X_1 = estimated land size in hectares,

Y_1 = garden eggs in kilograms (kgs.),

Y_2 = onions in kgs.,

Y_3 = peppers in kgs.,

Y_4 = tomatoes in kgs.,

( ) = t-value

* = .05 level of significance,

** = .01 level of significance,

n = number of observations,

$F0.05,4,109 = 5.66$

$F0.01,4,109 = 13.57$

The coefficients for onions, peppers, and tomatoes have the expected signs but that of garden eggs does not. The negative sign on the garden eggs coefficient implies that a one kilogram increase in garden egg production requires .0000195 hectare less land, other crop production unchanged. However, this coefficient is not significant at the .05 level. The other coefficients for crops (onion, pepper and tomatoes) and the intercept term were significant at the .01 level. As indicated by the R^2, 74 percent of the observed variance in land use can be explained by variation in production leaving only 26 percent unexplained.

Other estimating equations were explored including a quadratic equation without other inputs, a linear equation with other inputs included, and a quadratic equation including other inputs. The results of these regressions are presented in Table 4.6. The R^2's were higher than for the first linear model which is expected, since adding variables increases the R^2. In choosing which of these regression equations best estimates the land use relationship, a test of the significance of the contribution of the added terms were made. The evidence strongly suggests that in a

Table 4.6. Estimated Equations for Input X_1 - Land Use (Hectares).

	Model Equations							
	Linear		Quadratic		Linear with Other Inputs		Quadratic with Other Inputs	
Variables	Coeff.	T-Value	Coeff.	T-Value	Coeff.	T-Value	Coeff.	T-Value
	(.0000)		(.0000)		(.0000)		(.0000)	
Constant	631	3.64**	1130	4.78**	590	2.5*	818	3.48**
Garden Eggs Y_1	-.195	-1.08	-.765	-1.8	-.42	-2.3*	.886	1.9
Onions Y_2	.72	4.96**	-.05	-.14	.11	.62	-.562	-2.12*
Peppers Y_3	1.01	7.87**	1.7	6.74**	.535	3.88**	-.0015	- .006
Tomatoes Y_4	1.64	4.00**	2.2	.86	1.64	3.59**	-.43	.25
Y_1^2			.00025	2.24*			-.00011	-1.05
Y_2^2			.00046	4.18**			.00042	4.59*
Y_3^2			-.00059	-5.28**			.000032	.34
Y_4^2			-.0051	-1.46			-.0032	-1.44
Y_1Y_2			-.00054	-2.53*			-.0006	-4.98**
Y_1Y_3			.0001	.65			-.0001	- .77
Y_1Y_4			.0097	2.78**			.0058	3.1**
Y_2Y_3			.0003	1.64			.014	3.4**
Y_2Y_4			-.0069	-2.28*			-.0032	-1.66
Y_3Y_4			.0017	1.53			-.003	- .23

Table 4.6. (Continued)

Variables	Model Equations							
	Linear		Quadratic		Linear with Other Inputs		Quadratic with Other Inputs	
	Coeff.	T-Value	Coeff.	T-Value	Coeff.	T-Value	Coeff.	T-Value
	(.0000)		(.0000)		(.0000)		(.0000)	
Clearing X_2					-6.63	-.96	2.0	.35
Ploughing X_3					.727	.31	-.35	-.18
Planting X_4					- .414	-.14	3.87	.85
Lifting X_5					2.88	1.83	-.077	-.05
Opening X_6					-2.1	-.53	-3.6	-.97
Weeding X_7					3.9	.45	-1.38	-.18
Harvesting X_8					4.4	.72	-14.5	-2.74**
Water Use X_9					58.9		4.3	.29
R^2	.74		.86		.84		.93	

* indicates .05 level of significance
** indicates .01 level of significance

comparison of linear equation and the quadratic equation without other inputs, the additional quadratic terms contribute to the explanation of variation in land use. A comparison was made among the linear equation and the linear equation with other inputs added, the quadratic equation with other inputs included, the linear equation with other inputs and the quadratic equation with other inputs. Of the four equations, the quadratic equation with other inputs added best explains the relationship between land use and the other variables. However, the coefficients of the added inputs to the quadratic equation are not significant. Therefore, the quadratic equation without the other inputs added was deemed best.

Although the quadratic equation without the other inputs added was selected, it violates a basic assumption of linear programming, i.e., the relationship between inputs and outputs must be constant for all levels of a linear programming activity. The difficulty can be avoided easily by linear approximations. Activities for use in programming can be devised using various output combinations. Each of these satisfies the programming assumptions and combinations of these activities approximate the curvilinear relations implied by the quadratic function. The proposed model includes crop-combination activities of this type in the feasible set as the discussions in Chapter II model structure section suggests.

In order to obtain the equation for estimating land use, a linear equation which is homogeneous of degree one was chosen. Thus, a proportional increment in the variable factors will lead to a proportional increase in the outputs. The land coefficients were obtained by substituting each of the output combinations, which is defined in the feasible set, into equation 4.1. All the crop yield combinations resulting in negative land coefficients were excluded and the feasible output combinations are then normalized according to the land variable.

Labor

The labor data were recorded and coded weekly for each of the 114 farmers. The various field operations for which the labor data were recorded are as follows: (1) land preparation (clearing and ploughing); (2) planting activities after planting (lifting water, opening irrigation channels, and weeding); and (3) harvesting. The data recorded under each field operation include the class of labor (male adult, male child, female adult, female child in the case of family labor and Gaya, Jinga and Kawdogo in the case of hired labor), number of people, hours of working and total pay (in case of hired labor) as shown in Table 4.7.

Twenty-eight of the 114 farms reported using male child labor in opening irrigation channels and on rare occasions in clearing, weeding and lifting water with the shadoof device. Fifteen farms reported using the assistance of female child labor in opening irrigation channels and/or harvesting field operations. Five farmers reported employing the help of their adult female (wife) in opening irrigation channels and/or harvesting. Field operations such as ploughing, clearing and lifting water with shadoof, which requires more physical exertion, were performed by

Table 4.7. Type of Labor Information Recorded during 1978/79 Irrigation Season in Ringim LGA, Kano, Nigeria.

Description	Answers	Code	Column
	Hired Labor		
Days hired labor was used	No. of days	Actual	57
Land preparation: 11 Clearing and burning of wood and grasses			
Class of labor	Male Adult Male Child Gaya Jinga Kwadoga	1 2 3 4 5	58
Number of people working on the farm	Number	Actual	59-60
Hours of clearing and burning	Number in hours x 10	F4.1 Actual	61-64
Total pay	Naira x 100 e.g. 1.53 x 100 = 153	F5.2 Actual	65-69
	Family Labor		
No. of working days during the week	Number in days	Actual	8
Land preparation: 11 Clearing and burning of wood and grasses			
Class of labor	Male adult Male child Female adult Female child	1 2 3 4	9
Number of people working on the farm this week	Number	Actual	10-11
Number of hours of work --clearing and burning	Number in hours x 10 e.g. .5 = 5 1.5 = 15 11.5 = 115 112.5 = 1115	F4.1 Actual	12-15

the male adult member of the family in all cases. In the class of hired labor, gaya (communal labor) and kawdogo (daily paid labor) are the most popular. Gaya are employed mostly for planting, harvesting and opening irrigation channels field operations. Jinga (contract labor) are hired only for land preparations--clearing and ploughing. The daily paid labor is employed to work on any of the field operations.

The total hours of labor (family and hired) for each field operation was calculated for each farm. The procedure for obtaining the total hours of labor were presented schematically in Figure 4.2. The total hours of labor so obtained form the data base for determining the labor operations coefficient used in building the PP-CAM model.

In order to obtain labor coefficients of each field operation for the model, the hours of labor was regressed on the production of garden eggs, onions, peppers and tomatoes. The linear equations for estimating each of the field operations are presented in Table 4.8.

The coefficients of garden eggs, onions, peppers, and tomatoes, for ploughing, planting and opening channels operations have the expected signs and except for the tomato crop, the signs of the crops' coefficients for weeding and harvesting are positive. For the lifting operation, the coefficients of all the crops except garden eggs have negative signs. The negative sign on onions, peppers, and tomatoes implies that a one kilogram increase in the production of onions or peppers or tomatoes requires .0258, .00295, .0329 hours less labor, respectively, with other crop production unchanged. However, of the three crops only the coefficient for onions is significant at the .05 level.

Except for the lifting operation, the R^2 obtained for the other labor use operations range from 58 percent for ploughing to 80 percent for harvesting. The low R^2 of 16 percent associated with the lifting operation means that 84 percent of the observed variance in labor use in this operation could not be explained by variation in production. The low value of F suggests that there is no relationship between lifting labor use operation and output of crops. This probably results partly from combining all farms in this analysis which confound the difference in labor required by pump and shadoof. Also with shadoof alone it is partially a function of the depth of the water source which is unrelated to yield.

The labor use coefficients for each of the field operations was obtained by substituting the output combinations normalized according to the land variable into the labor use equations for clearing, ploughing, planting, lifting, opening irrigation channels, weeding, and harvesting operations.

The timing of operations can be important in a model dealing with decision making. The model for this study has been constructed to represent one irrigation season (October to May), starting with land preparation clearing and ploughing and ending with harvesting and selling the crops. The starting date of the irrigation season varies

LABOR DATA

Family labor (hrs.) | Hired labor (hrs.)

Summed by activities (X_2 to X_8) | Summed by activities (X_2 to X_8)

Total Sum by Activities (X_2 to X_8)

Labor Used in Each Activity Regressed on Yield Data

$$X_i^{\underline{a}/} = f\,(Y_1, Y_2, Y_3, Y_4)^{\underline{b}/} \quad i = 2,3, \ldots 8$$

Yield Combinations in Feasible Set Substituted into Each Equation

Input Coefficients

Figure 4.2. Schematic of Labor Data Analysis.

a/ Where
X_2 = clearing, X_3 = ploughing, X_4 = planting, X_5 = lifting, X_6 = opening, X_7 = weeding, and X_8 = harvesting.

b/ Where
Y_1 = garden eggs, Y_2 = onions, Y_3 = peppers, Y_4 = tomatoes.

Table 4.8. Estimated Coefficients in Linear Equations for Clearing, Ploughing, Planting, Lifting, Opening, Weeding, and Harvesting Labor Use Hours.

	Coefficients in Equation					
	Clearing		Ploughirg		Planting	
Variables	Coef. (.0000)	T-Value	Coef. (.0000)	T-Value	Coef. (.0000)	T-Value
Constant	188030	5.46**	569590	6.00**	443850	5.21**
Garden Egg Y_1	109	3.02**	495	5.00**	386	4.35**
Onions Y_2	46.5	1.61	73.2	.92	17.1	.24
Peppers Y_3	88.5	3.47**	48.2	.69	253	4.01**
Tomatoes Y_4	437	5.35**	744	3.31**	846	4.19**
R^2	.67		.60		.69	

Table 4.8. (Continued)

	Coefficients in Equation							
	Lifting		Opening		Weeding		Harvesting	
Variables	Coeff.	T-Value	Coeff.	T-Value	Coeff.	T-Value	Coeff.	T-Value
	(.0000)		(.0000)		(.0000)		(.0000)	
Constant	1878830	12.09**	492490	4.07**	105060	4.13**	194790	6.56**
Garden Egg Y_1	613	3.78**	365	2.89**	110	4.13**	219	7.05**
Onions Y_2	-258	-1.98*	581	5.72**	61.4	2.89**	92	3.69**
Peppers Y_3	-29.8	-.26	402	4.49**	25.2	1.34	89	4.05**
Tomatoes Y_4	-329	-.89	207	.72	-4.02	.007	-138	-1.96*
R^2	.16		.76		.58		.80	

* indicates .05 level of significance.
** indicates .01 level of significance.

among the farmers from the last week of October through the last week in December. The length of the season ranged from 19 weeks to 28 weeks. In order to ascertain if there is any predictable effects of the starting date and length of season on the yield and the crop combination grown, the farmers were categorized as shown in Table 4.9. The starting date and length of season do not appear to affect the presence or absence of any crop. Scatter diagrams of the average yield in kilograms/hectare and the associated length of season as depicted in Figures 4.3a, b, c, d for garden eggs, onions, peppers, and tomatoes, respectively, reveal no obvious patterns in the influence of the length of growing season on the crop yield.

Hypothesizing, therefore, that the length of growing season, and the starting date had no perceptible influence on yield outcome, then any period can be defined for labor usage. Consequently, four monthly labor use periods were defined for this study--October to December, January, February, and March to May periods.

In order to obtain the monthly labor use coefficients for the model, the labor hours were regressed on the crop production. The linear equations for estimating labor use in each period are presented in Table 4.10. The signs of the coefficients for the crops were positive for the four monthly labor use periods, except for the sign on the tomato coefficient of the February period and the peppers and tomatoes coefficients of the March-May period. These negative coefficients were not significant at the .05 level. The R^2's obtained were 64 percent for October-December period, 37 percent for January, 51 percent for February and 35 percent for March-May. The labor use coefficients for each of the monthly periods were obtained by substituting each of the output combinations normalized according to the land variable into the estimated equations in Table 4.10.

The monthly labor use for each period is constrained in the model by the number of work days and the number of people in the family available to help on the irrigation farm. Five working days per week excluding the number of public holidays is assumed to be the available work days. A seven-hour day of 8 a.m. to 12 noon and 3 to 6 p.m. or 9 a.m. to 1 p.m. and 3 to 6 p.m. as reporeted by the farmers defines the available hours of labor per day. The available hours per person working on the farm are 322 hours in October-December period, 133 hours in January, 140 hours in February, and 308 hours in March-May. The number of persons available for irrigation in the family as reported by the farmers are summarized in Table 4.12. The number of children in the family ranges from 0 to 13 children with an average of two children per family. The number of male children (15 years or older) in the family participating in irrigation ranges from 0 to 5 with an average of one adult child per family. The average number of children in the family as reported by farmers operating shadoof lift systems is two with one adult male participating in irrigation. The average number of children in the family as reported by farmers oprating pump systems is six with two adult male children participating in irrigation.

Table 4.9. Starting Date, Length of Season, and the Cropping Patterns as Reported by 114 Farmers in Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Week No.		Length of Season	No. of	Average Yield in Kilograms per Hectare			
Begins	Ends	in Weeks	People	Garden egg	Onion	Pepper	Tomato
1	19	19	1	7014	9099	16919	0
1	20	20	4	8053	8550	7500	396
1	21	21	7	6487	9493	8538	506
1	22	22	5	3599	2981	4930	153
1	23	23	1	10767	8465	3380	1054
1	24	24	1	3341	10024	165	0
1	25	25	5	2490	3745	3168	694
1	26	26	9	4776	5441	4925	249
1	27	27	15	5019	5332	5449	521
1	28	28	1	5026	5128	598	222
2	22	21	1	2456	952	1232	157
2	23	22	1	3944	8000	322	1139
2	25	24	5	3126	7236	1116	466
2	26	25	19	4137	7689	1184	402
2	27	26	15	4071	7021	1031	227
2	28	27	1	5820	26393	9508	0
3	25	23	1	4896	7713	161	0
3	26	24	1	2954	6264	167	86
3	27	25	1	2784	4118	275	0
4	23	20	1	1981	2121	902	219
4	24	21	1	1193	2420	1714	0
4	27	24	2	3105	4933	2873	0
5	26	22	5	4083	10476	1116	409
7	26	20	2	2548	4580	2081	412
7	27	21	1	871	5059	1200	424
7	28	22	1	1805	4098	622	0
8	26	19	2	1641	11585	2056	0
8	27	20	3	3744	6778	1318	946
9	27	19	1	763	4948	1052	0

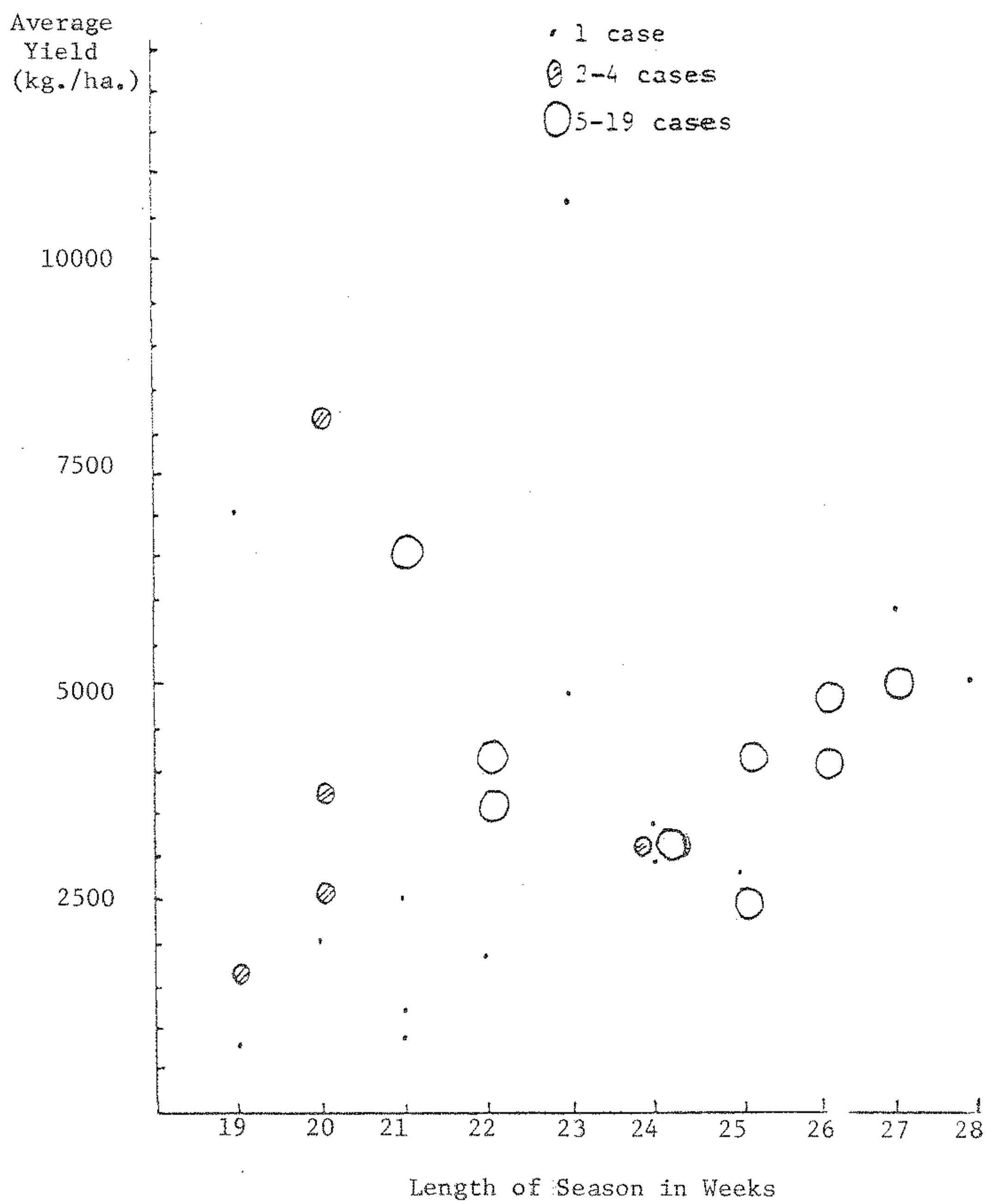


Figure 4.3a. Scatter Diagram of Average Yield (kg/ha) of Garden Eggs and Length of Season.

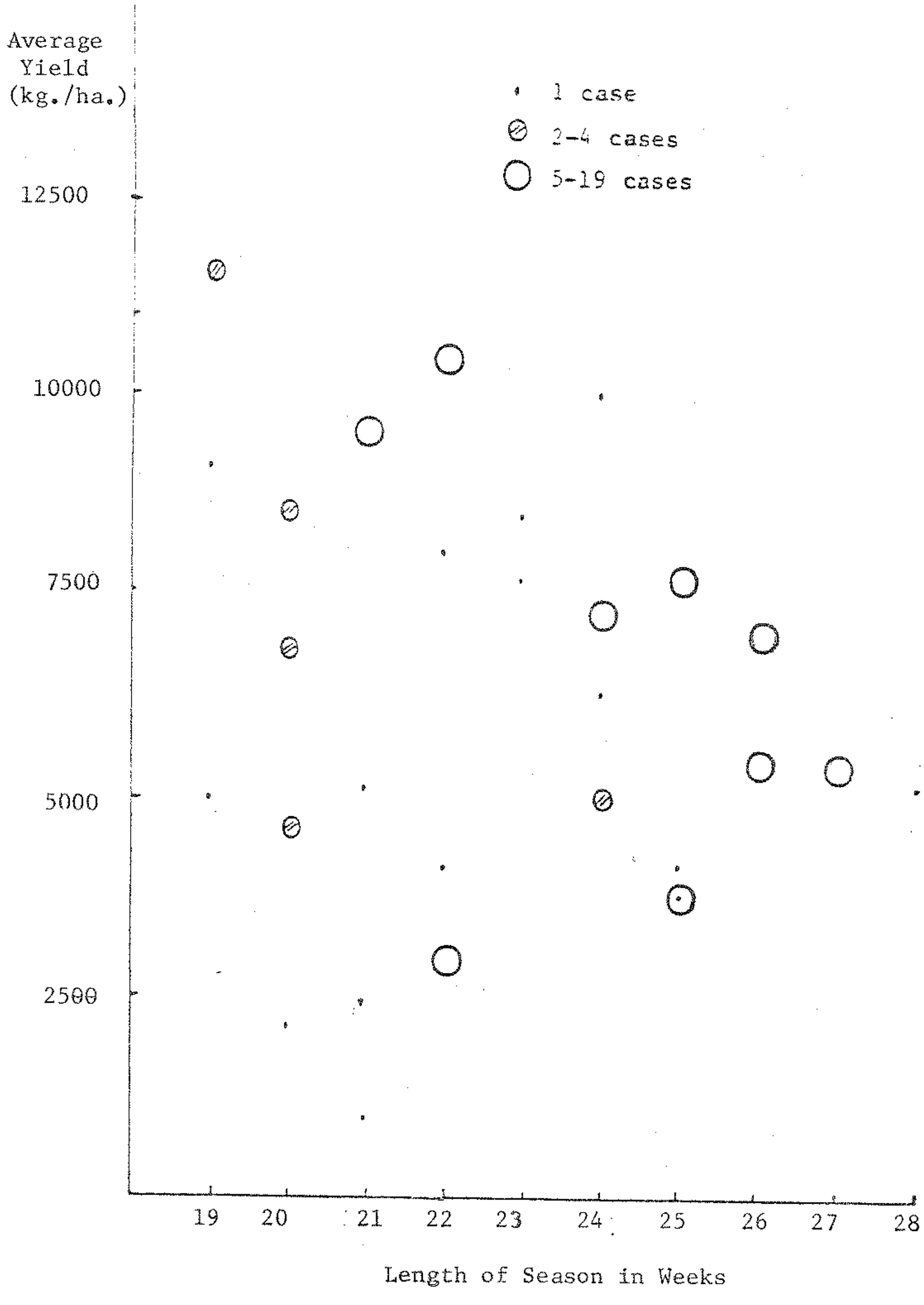


Figure 4.3b. Scatter Diagram of Average Yield (kg/ha) of Onions and Length of Season.

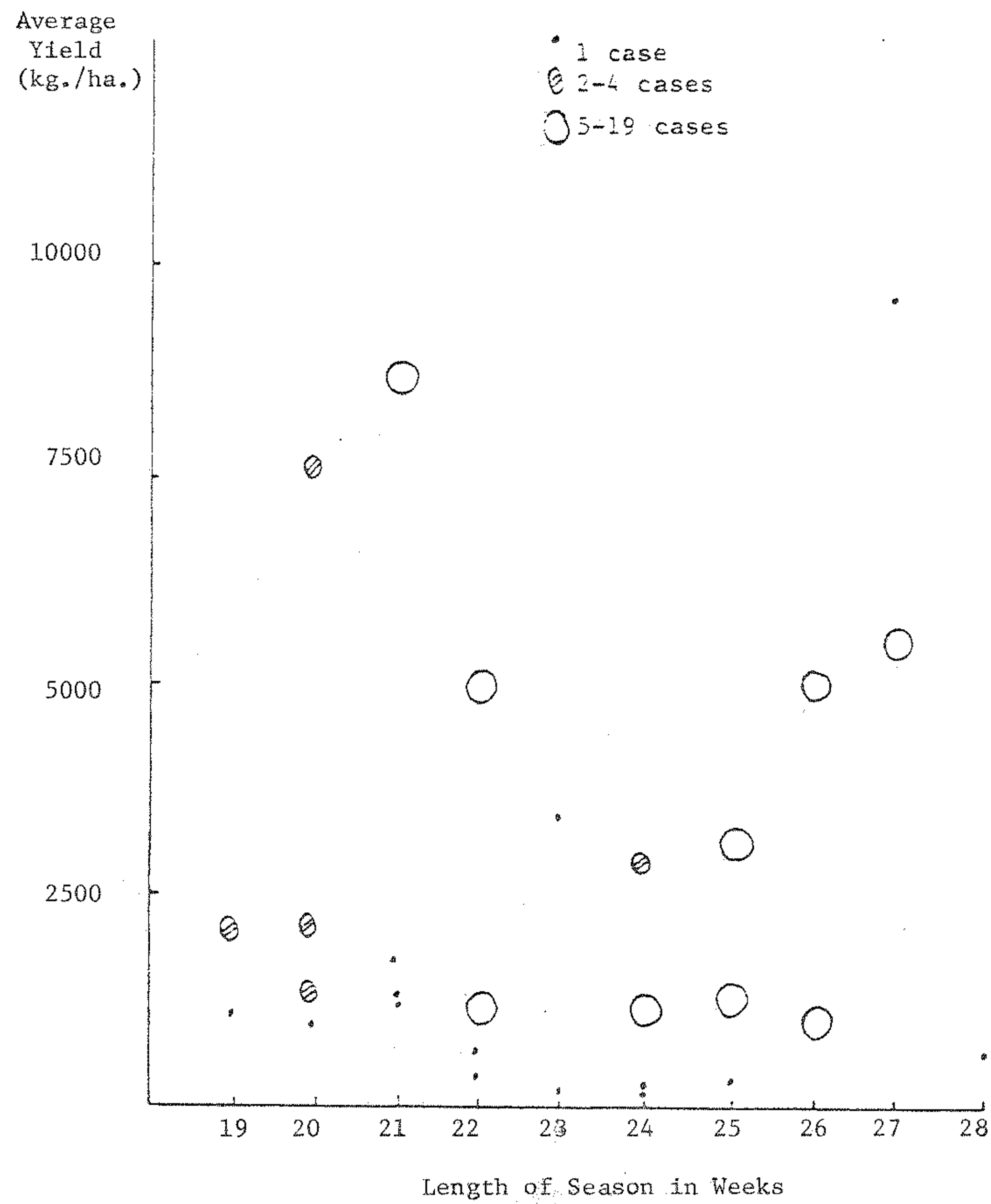


Figure 4.3c. Scatter Diagram of Average Yield (kg/ha) of Peppers and Length of Season.

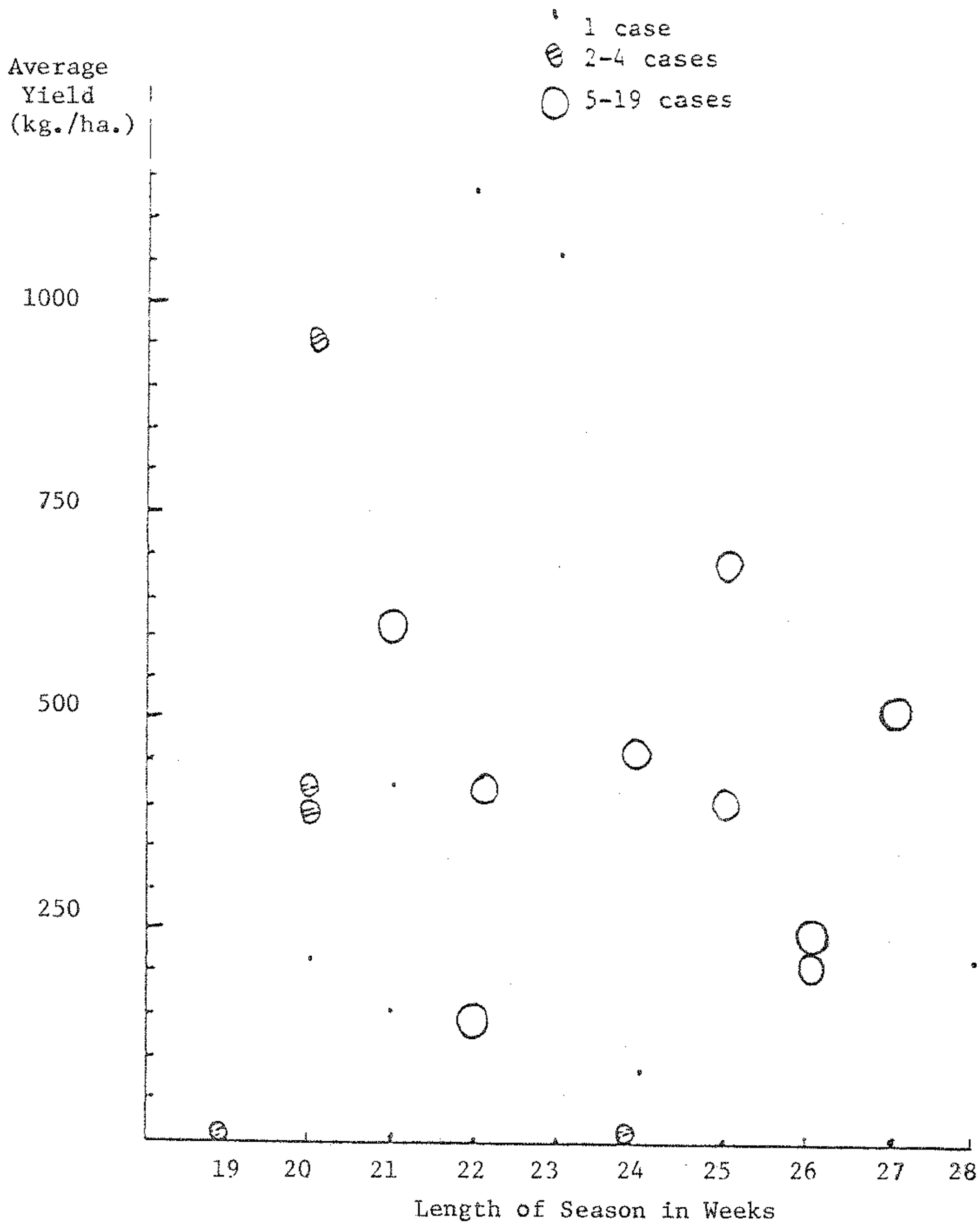


Figure 4.3d. Scatter Diagram of Average Yield (kg/ha) of Tomatoes and Length of Season.

Table 4.10. Estimated Linear Equations for Monthly Labor Use October-December, January, February, March-May in Hours.

	Linear Model Equations							
	Oct.-Dec.		January		February		March-May	
Variables	Coef.	T-Value	Coef.	T-Value	Coef.	T-Value	Coef.	T-Value
	(.0000)		(.0000)		(.0000)		(.0000)	
Constant	1879652	6.1**	514090	5.15**	503570	6.67**	972867	9.76**
Garden Egg Y_1	1383	4.31**	245	2.35**	284	3.61**	378	3.64**
Onion Y_2	218.9	.85	157	1.87	83.6	1.32	155	1.85
Pepper Y_3	796	3.49**	1.72	.02	129	2.31*	54.8	-.74
Tomato Y_4	1400	1.92	567	2.4*	-99.3	-.56	-89.4	-.38
R^2	.64		.37		.51		.35	

* indicates .05 level of significance.
** indicates .01 level of significance.

Table 4.11. Available Working Hours per Person for the Periods October-December, January, February, and March-May, Ringim LGA, Kano, Nigeria, in 1978/79.

Periods	Work Days	Holidays	Available Work Days	Available Working Hours (Avail. Days x 7)
October-December	50	4	46	322
January	20	1	19	133
February	20	0	20	140
March-May	47	3	44	308

Table 4.12. Frequency Distribution of Children per Family and the Male Children[c/] Participating in Irrigation Activities on 112[b/] Farms, Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Number of Children	Frequencies: Pump Users: All Children	Pump Users: Available[a/]	Shadoof: All Children	Shadoof: Available[a/]	Overall: All Children	Overall: Available[a/]
0		1	32	59	32	60
1		3	21	23	21	26
2		1	24	12	24	13
3	3	4	11	5	14	9
4	1		3	2	4	2
5	2	1	5	1	7	2
6			4		4	
7	1		2		3	
8	1				1	
11	1				1	
13	1				1	
Total cases	10	10	102	102	112	112
Mean	6	2	2	1	2	1

a/ Male children 15 years and over (adults) are available for irrigation.

b/ Two farms out of 114 did not respond.

c/ Female children (15 years and over) are married and unavailable.

Hired labor was available at a minimum hourly wage rate. This wage was Nigeria's minimum wage rate of N60/month or N2/day in 1978/79. On an hourly basis this amounts to 29 Kobo. This hourly wage rate is assumed paid by the farmers in October-December and January periods when hired labor is in heaviest demand for clearing, ploughing, and lifting water field operations. During the weeding and harvesting field operation periods, February and March-May, a 25 percent hourly wage discount or 22 Kobo/hour is assumed in the model. This is approximately the wage differential observed. In 1981/82 the minimum monthly wage rate in Nigeria became N120 or N4/day. The hourly wage rate is 57 Kobo for October to January and 43 Kobo for February to May. These average wage rates in Table 4.13 are similar to those used by Balcet and Chandler in their research project, as presented in Table 4.14.

Water Use

The water use data was estimated to be 4542 liters per hour for the shadoof system and 44965.8 literes per hour for the pump system.1/ The hours of irrigation data were coded according to the days of irrigation from Saturday through Friday. For farmers owning two shadoofs the hours of irrigation for the days both were operated is doubled. The total hours of irrigation for the season were converted into hectare-centimeters (Ha-cm) of water use by dividing the total liters by 100000.

A total of 2033 ha-cm of water were applied by the 114 farmers with usable data. Fifty-four percent of the water (1107 ha-cm) was applied by the farmers using motor driven pumps and the rest (926 ha-cm) by farmers with shadoof lift devices (Table 4.15). The water applications with shadoof ranges from about 2 to 31 ha-cm with 9 ha-cm as the average water applied. The water applications with pump ranges from 26 to 209 ha-cm with 111 ha-cm as the average water applied. The average water application for all the farmers reporting was about 18 ha-cm.

In order to obtain water use coefficients for the model, the water applications were regressed on the production of garden eggs, onions, peppers and tomatoes. The equation for estimating water use is

$$4.2.\quad X_9 = \underset{(-3.49)^{**}}{-7.243} + \underset{(.28)}{.00605\,Y_1} + \underset{(7.48)^{**}}{.013\,Y_2} + \underset{(6.44)^{**}}{.0099\,Y_3} + \underset{(1.67)}{.0082\,Y_4}$$

$R^2 = .78$ F-statistic = 78.4 n = 114

1/ These conversions were discussed in Chapter III under the characteristics of water lift devices and irrigation systems.

Table 4.13. Average Cost of Hired Labor per Hour by Period for the Years 1978/79 and 1981/82.

Year	Period	Daily Wage Rate (Naira)	Hourly Wage Rate (Kobo)
1978/79	October-December	2	29
	January	2	29
	February	1.5	22
	March-May	1.5	22
1981/82	October-December	4	57
	January	4	57
	February	3	43
	March-May	3	43

Table 4.14. Average Cost of Hired Labor at Selected Projects in Nigeria, 1976-79.

Project/ Year	Weekly Period	Kobos per Hour
Gusau 1976/77	April 4 - May 30	15.5
	May 31 - August 29	18.7
	August 30 - January 30	14.3
	January 31 - April 3	8.1
	Annual average	15.4
Gusau 1977/78	April 1 - May 26	26.6
	May 27 - August 25	34.0
	August 26 - January 26	22.1
	January 27 - May 30	16.5
	Annual average	26.8
Funtua 1976/77	April 4 - May 30	11.1
	May 31 - August 29	17.2
	August 30 - January 30	12.5
	January 31 - April 3	8.0
	Annual average	13.9
Funtua 1977/78	April 1 - May 26	29.1
	May 27 - August 25	33.3
	August 26 - January 26	22.5
	January 27 - March 30	13.2
	Annual average	22.5
Gombe 1977/78	April 1 - May 26	25.6
	May 27 - August 25	33.7
	August 26 - January 26	30.5
	January 27 - March 30	23.0
	Annual average	30.7
Gombe 1978/79	April 3 - May 28	33.8
	May 29 - August 27	48.6
	August 28 - January 28	36.0
	January 20 - April 1	26.0
	Annual average	35.9

Source: Adapted from Balcet and Chandler, 1981 [9].

Table 4.15. Water Used by 114 Farmers with Shadoof and Pump Irrigation in Ringim LGA, Kano, Nigeria during the 1978/79 Irrigation Season.

Lift Devices	No. of Cases	Total (ha-cm)	Total (%)	Water Use Minimum (ha-cm)	Water Use Maximum (ha-cm)	Water Use Average (ha-cm)
Shadoof farms	104	926.3	46	1.8	31.2	8.9
Pump farms	10	1106.7	54	26.2	209.1	110.7
All farms	114	2033.	100	1.8	209.1	17.8

where

X_9 = water use in hectare-centimeter,

Y_1 = garden eggs in kilograms,

Y_2 = onions in kilograms,

Y_3 = peppers in kilograms,

Y_4 = tomatoes in kilograms,

( ) = t-value,

* = .05 level of significance,

** = .01 level of significance,

n = number of observations,

$F_{0.05,4,109} = 5.66$

$F_{0.01,4,109} = 13.57$

The coefficient for the crops have the expected signs. As indicated by the R^2, 78 percent of the observed variance in water usage can be explained by variation in production leaving 22 percent unexplained. To obtain the water use coefficients for the model, each of the output combination normalized according to the land variable were substituted into equation 4.2.

Capital Investment and Costs

Capital Investment

The amount of capital investment needed to purchase the pump and to construct the shadoof were reported by the farmers (Table 4.16). The capital investment for the pump ranged from N500 to N850 with N688 as the average investment. The investment varied primarily because of time of purchase. The capital investment for constructing the shadoof ranged from 0 to N45 with an average investment of N16. The farmers with zero construction cost, constructed the shadoof themselves from materials already in hand.

Table 4.16. Capital Investment and Costs for Ten Pump Farms and An Average of 114 Shadoof Farms, Ringim LGA, Kano, Nigeria in the 1978/79 Irrigation Season.

Item	Pump Farm Numbers b/							
	5	7	12	13	14	26	30	39
Hectares Served	1.413	1.229	.211	1.266	1.077	.129	.665	1.386
Capital Investment (N)	600	560	660	832	844	850	800	630
Expected Useful Life (yrs.)	8	8	8	8	8	8	8	8
Depreciation (N)	75	70	82.5	104	106.25	106.25	100	78.75
Interest on Investment at 6% (N)	36	33.6	39.6	49.92	51	51	48	37.8
Total Fixed Cost (N)	111	103.60	121.10	153.92	156.14	157.25	148	116.55
Fuel or Petrol Cost per Hectare (N)	122.33	99.55	98.44	127.21	79.16	62.56	87.71	40.27
Repair, Maintenance and Lubricants Cost per Hectare (N)	20.18	35.96	---	67.14	31.01	31.01	49.62	12.27
System Operating Cost/ Hectare (N)	142.51	135.51	98.44	194.35	110.17	93.57	137.33	52.54
Other a/ Variable Cost/ Hectare (N)	13.10	41.91	41.70	18.96	26	79.52	---	---
Total Variable Cost/ Hectare (N)	155.61	177.42	140.14	213.31	136.17	171.09	137.33	52.54
Total Cost per Hectare (N)	266.61	281.02	261.24	369.23	292.31	328.34	285.33	169.09

a/ Other variable costs include seed cost, fertilizer cost, product transport to market cost and fencing materials cost.

b/ Number used corresponds to the coding sheet.

c/ Based on 104 farms.

Table 4.16. (Continued)

Item	Pump Farm Numbers[b]		Average	
	40	41	Pump	Shadoof[c]
Hectares Served	.635	.331	.8342	.1709
Capital Investment (N)	600	500	687.60	15.58
Expected Useful Life (yrs.)	8	8	8	4
Depreciation (N)	75	62.50	85.95	3.96
Interest on Investment at 6%(N)	36	30	41.26	.93
Total Fixed Cost (N)	111	92.50	127.21	4.89
Fuel or Petrol Cost per Hectare (N)	105.35	175.17	99.78	--
Repair, Maintenance and Lubricants Cost per Hectare (N)	20.47	33.23	30.09	.91
System Operating Cost/ Hectare (N)	125.82	208.40	129.87	.91
Other[a] Variable Cost/ Hectare (N)	20.48	12.08	25.18	112.76
Total Variable Cost/ Hectare (N)	146.30	220.48	155.05	113.67
Total Cost per Hectare (N)	257.30	312.98	282.26	118.56

a/ Other variable costs include seed cost, fertilizer cost, product transport to market cost, and fencing materials cost.
b/ Number used corresponds to the coding sheet.
c/ Based on 104 farms.

Irrigation Fixed Cost

The fixed costs are incurred whether or not the system is used. These include depreciation, and interest on investment as shown in Table 4.17. Depreciation, which is defined as the loss in value of a capital asset over time due to age, obsolescence, and use, was calculated using the straight line method, with an estimated life of eight years for the pump and four years for the shadoof. No salvage value was used. The useful life for the pump was that given by the distributors of the system and that of the shadoof was an average of that reported by the farmers. Fixed cost for the pump ranges from N92 to N157 with average fixed cost of N127. The average fixed cost for the shadoof farm is N5.

Irrigation Variable Cost

The variable costs include system operating costs and other variable costs (seed, fertilizer, product transport to market, and fencing materials). The operating costs are directly related to the use of the system. They include cost of fuel, repairs, maintenance and lubricants. Labor costs for attending the pump and lifting water with shadoof appear later in the results chapter. One percent of total construction cost of the shadoof was assumed as the maintenance cost. This is approximately the maintenance cost observed in the study area. The operating cost per hectare for the pump ranged from N53 to N208 with an average cost of N130.00 (Table 4.16). The shadoof, which uses no petrol or fuel, has an average operating cost per hectare of only one Naira.

The average of the other variable costs per hectare for the systems were N25 and N113 for the pump and shadoof farmers, respectively. The higher cost associated with shadoof farmers resulted from the purchase of seeds which made up 80 to 90 percent of the other variable cost category. The pump farmers obtain the seeds needed from the previous year's harvest. Apparently the shadoof farmers with small areas of a fraction of a hectare find purchase of the few seeds needed convenient. Pump farmers with larger areas and a greater seed requirement seem to find it profitable to grow their own. The average total variable cost per hectare for the systems were N155 and N114, respectively, for the pump and shadoof farmers with the average total costs including fixed and total variable costs of N282 and N118.

PRESENTATION OF THE RESULTS

This section is a presentation of the model result. The PP-CAM is a linear programming model with 186 columns and 19 rows. The derivation of the technical coefficients needed were discussed in the previous section on data analysis. Experiments with this model were designed to assess the impact of possible changes in the economic and technical environment of the farmers. These involved varying water, land and labor. The impacts of these experiments on the costs and returns structure of small scale shadoof and pump lift irrigation systems were estimated. This procedure indicates the role of water, land and labor as decision variables in the farmer's choice of a water lift system.

Analysis of Water Lifting Costs

The annual costs of lifting water for irrigation using shadoof and pumps are of two kinds: (1) fixed costs which accrue regardless of use of the device and (2) operating costs directly related to the operation of the device. The data presented under the operating cost (Chapter IV) excluded the labor costs for lifting water with shadoof and the labor used attending the pump system.

In order to ascertain the amount of lifting labor and the ha-cm of water used on one hectare of land, the model was used with a specification of one hectare of land irrigated and with labor resources unconstrained. The result indicated that 1855 hours of lifting is required for delivering 156 ha-cm of water needed on one hectare of land. About a tenth of the lifting hours or 185.5 hours is associated with attending to the pump system. This result and the fixed and variable costs (Table 4.16) were used to compute the variable costs per ha-cm of water lifted (Table 5.1) and the average total cost per ha-cm of water presented in Table 5.2 and 5.3 for shadoof and pump, respectively.

The data in Table 5.2 and Table 5.3 are plotted in Figure 5.1. For lifting volumes of water between 1 and 51 ha-cm, the shadoof is the least cost system per unit of water lifted. When the volume of water required exceeds 51 ha-cm the pump is the most economical device. In practice the maximum volume of water lifted by the farmers using the shadoof was 31 ha-cm. This is comparable to the findings of Molenaar, i.e., the volume of water lifted using the shadoof seldom exceeds 30 ha-cm and about 50 ha-cm capacity for farms operating two shadoofs [33]. For more than 30 ha-cm, two shadoofs are needed on the farm. Adding a third shadoof to exceed 50 ha-cm is not economically efficient as is evident in Figure 5.1. For more than 50 ha-cm of water usage the pump becomes the least-cost water lift system. If the pump system were in use at the maximum capacity of 750 liters per minute throughout the 903 hours available in the season, 400 ha-cm of water would be delivered to the field. Therefore, to deliver more than 400 ha-cm of water to the farm, two pumps have to be used.

Table 5.1. Estimation of Water Lifting Costs for the Shadoof and Pump Systems, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Type of System	Item	Cost
Shadoof lift	1. Fixed cost (Table 4.17)	N 4.89
	2. Variable costs per ha-cm of water	
	(a) Man-Labor 1855 hrs./ha. divided by 156 ha-cm/ha = 11.89 hrs./ha-cm (11.89 hours at N.29)	3.45
	(b) Repairs (N.91/ha. divided by 156 ha-cm/ha.)	.01
	Variable cost per ha-cm of water	N3.46
Pump lift	1. Fixed cost (Table 4.17)	N127.21
	2. Variable costs per ha-cm of water	
	(a) Operating variable cost excluding labor (N129.87/ha. divided by 156 ha-cm/ha)	.83
	(b) Man-labor for attendance 185.5 hrs./ha. divided by 156 ha-cm/ha = 1.189 hrs./ha-cm (1.189 hrs. at N.29)	.34
	Variable cost per ha-cm of water	N 1.17

Table 5.2. Total Annual Cost of Lifting Water with Shadoof Systems, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Volume of Water Lifted	Fixed Cost per ha-cm	Variable Cost per ha-cm	Average Total Cost per ha-cm		
			One Shadoof	Two Shadoofs	Three Shadoofs
(ha-cm)	(N)	(N)	(N)	(N)	(N)
2	2.45	3.46	5.91	8.36	10.81
5	.98	3.46	4.44	5.42	6.46
10	.49	3.46	3.95	4.44	4.93
20	.25	3.46	3.71	3.96	4.21
30	.16	3.46	3.62	3.78	3.94
40	.12	3.46	3.58	3.70	3.82
50	.10	3.46	3.56	3.66	3.76
60	.08	3.46	3.54	3.62	3.70

N = Naira

Table 5.3. Total Annual Cost of Lifting Water with Pump Systems, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Volume of Water Lifted (ha-cm)	Fixed Cost per ha-cm (N)	Variable Cost per ha-cm (N)	Average Total Cost/ha-cm: One Pump (N)	Average Total Cost/ha-cm: Two Pumps (N)
2	63.61	1.17	64.78	128.39
5	25.44	1.17	26.61	52.05
10	12.72	1.17	13.89	26.61
20	6.36	1.17	7.53	13.80
30	4.24	1.17	5.41	9.65
40	3.18	1.17	4.35	7.53
50	2.54	1.17	3.71	6.25
60	2.12	1.17	3.29	5.41
100	1.17	1.17	2.44	3.71
200	.64	1.17	1.81	2.45
300	.42	1.17	1.59	2.01
400	.32	1.17	1.49	1.81
500	.25	1.17	1.42	1.67

N = Naira

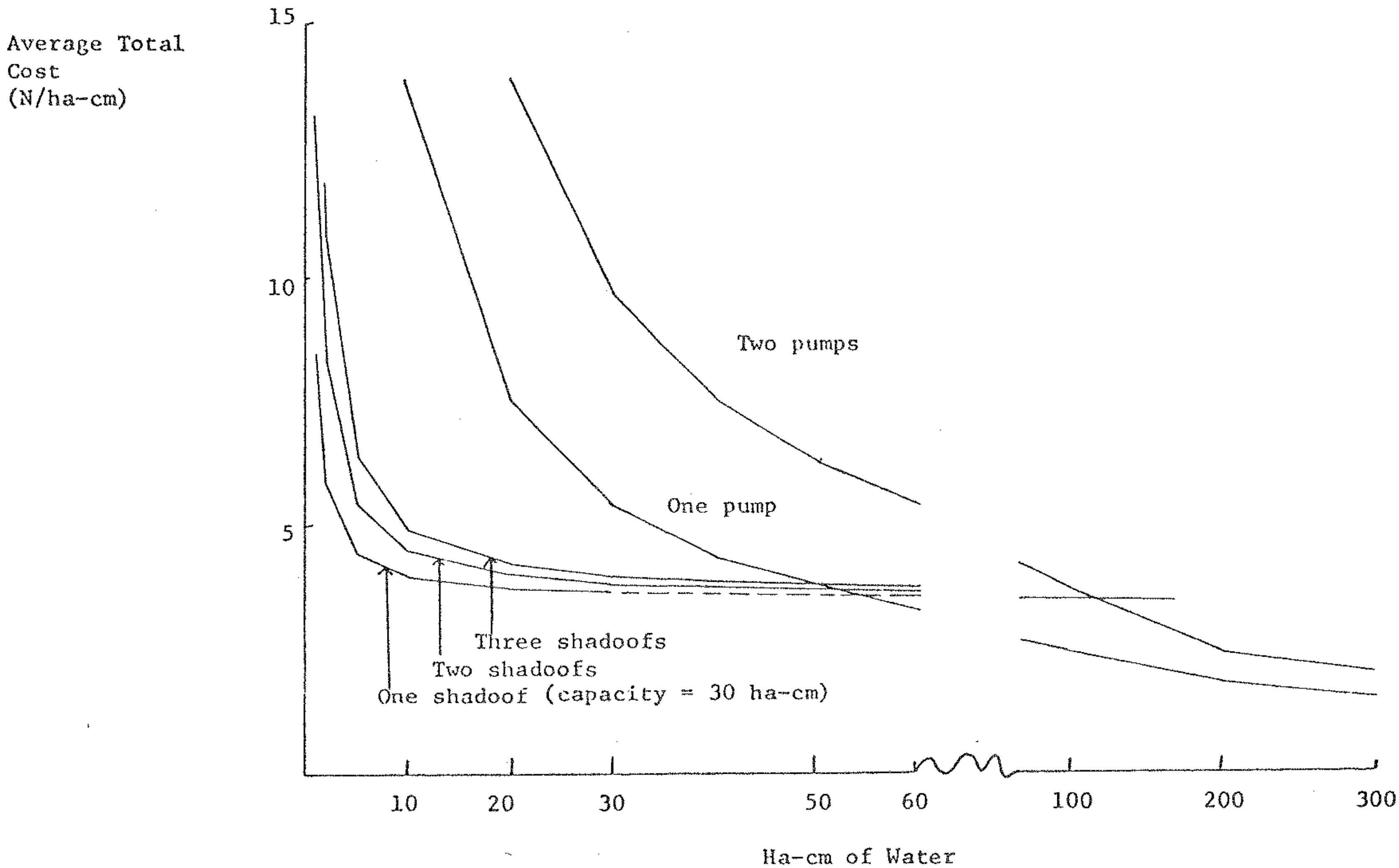


Figure 5.1. Relationship between Average Total Cost per Ha-cm and Volume of Water Lifted.

In order to answer the question of how much land should be irrigated to justify use of a pump, the model was used with the maximum water delivered by the systems as constraints. The estimated maximum land areas were obtained as shown in Table 5.4. A single shadoof is the least costly method for land areas of .192 hectare and less. Two shadoofs have lower average costs between .192 and .32 hectare. For a land area greater than .32 hectare, the use of pump lift systems is the least costly. However, additional pumps are required for land areas greater than 2.564 hectares.

These facts indicate that the shadoof system users who expressed willingness to irrigate two hectares in the upland farm if water were available would have to switch to a pump lift system in order to be efficient on a cost basis. The pump system users willing to irrigate six hectares in the upland would need at least two to three pumps to deliver the amount of water required. The facts also suggest that, if the government is to supply water for irrigating upland, a water source designed to supply at least 156 ha-cm per hectare is economically optimum given the situation that existed in 1978/79.

Impact of Resource Constraints on Returns to Labor and Management

The impact of resource constraints on the cost and return structure of the lift system were analyzed based on 10 levels of hectares of land (.1, .2, .3, .5, .8, 1, 1.5, 2, 3, 6), 10 levels of ha-cm of water (2, 10, 20, 30, 50, 100, 200, 300, 400, 800), and full time family workers 15 years old or older (1, 2, 3). Variation in the model results were obtained using all possible combinations of these levels.

Returns to Varying Land and Water with the Amount of Labor Unchanged

Various levels of water and land resources were specified in this experiment with the model assuming that family labor is unchanged at two men or 1806 hours (Table 4.7). The estimated returns to labor and management are presented in Tables 5.5 and 5.6 for shadoof and pump farms, respectively.

Within the land and water constraints of the shadoof system the estimated maximum returns to labor and management were N1179 (65 Kobo per hour) for single shadoof user and N1728 (97 K/hour) for a two-shadoof user. These returns are very profitable compared to the opportunity cost of labor which is 29 Kobo per hour. Irrigating with two shadoofs is to the benefit of the farmer since the marginal return of 32 Kobo per hour reasonably compensate for the added hours of lift labor used. If the quantity of water available in the area is limited to two ha-cm, the maximum return of N104 by a single shadoof farmer makes irrigation farming unprofitable. The shadoof users with an average water use of 10 ha-cm and about .2 hectare have an estimated return to labor and management of N506. Irrigating .1 hectare of land with the 10 ha-cm of water would have earned a higher return of N517 and saved the added variable cost needed on .2 hectare of land.

Table 5.4. Estimated Water, Land and Labor Used, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Volume of Water Lifted (ha-cm)	Land Area Irrigated (ha)	Shadoof Lift Labor (hr.)	Pump Attendance Labor (hr.)
2	.011	70	7.0
5	.023	175	17.5
10	.056	350	35.0
20	.119	517	51.7
30	.186	532	53.2
40	.255	510	51.0
50	.321	595	59.5
100	.641	1189	119.0
156	1.000	1855	185.5
234	1.500	2783	278.3
312	2.000	3710	371.0
468	3.000	5565	556.5

Table 5.5. The Returns to Labor and Management Related to Various Levels of Water and Land under the Shadoof Lift Systems, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Water Used (ha-cm)	Shadoofs (no.)	Returns to Labor and Management with the Following Land Use: .1 ha. (N)	.2 ha. (N)	.3 ha. (N)	.5 ha. (N)	.8 ha. (N)	1 ha. (N)
2	1	104.32	92.96	81.59	58.85	24.85	2.02
	2	99.32	88.07	76.70	53.85	19.96	-2.87
10	1	517.13	505.77	494.40	471.66	437.66	414.83
	2	512.24	500.88	489.50	466.77	432.77	409.94
20	1	765.77	845.18	833.81	811.07	777.07	754.24
	2	760.88	840.29	828.92	806.18	772.18	749.35
30	1	765.77	1178.59	1167.22	1144.48	1110.48	1087.65
	2	760.88	1173.70	1162.33	1139.59	1105.59	1082.76
50	1	765.77	1178.59	1167.22	1144.48	1110.48	1087.65
	2	760.88	1247.37	1723.29	1796.45	1762.45	1739.62
100	1	765.77	1178.59	1167.22	1144.48	1110.48	1087.65
	2	760.88	1247.37	1723.29	1796.45	1762.45	1739.62

N = Naira

Table 5.6. The Returns to Labor and Management Related to Various Levels of Water and Land under the Pump System, Ringim, LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Water Used (ha-cm)	Pumps (no.)	Returns to Labor and Management with the Following Land Use									
		.1 ha.	.2 ha.	.3 ha.	.5 ha.	.8 ha.	1 ha	1.5 ha.	2 ha.	3 ha.	6 ha.
2	1	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0
10	1	390.67	375.17	359.66	328.85	282.14	251.13	173.6	96.08	0	0
	2	263.40	247.96	232.45	201.64	154.93	123.92	0	0	0	0
20	1	639.31	714.58	699.07	668.06	621.55	590.54	513.01	435.49	280.44	0
	2	512.10	587.37	571.86	540.85	494.34	463.33	385.80	308.20	153.23	0
30	1	639.31	1047.99	1032.48	1001.47	954.96	923.95	846.42	768.90	613.85	148.70
	2	512.10	920.78	905.27	874.26	827.75	796.74	719.21	641.69	486.64	21.49
50	1	639.31	1121.66	1593.44	1658.33	1161.82	1580.81	1503.28	1425.76	1270.21	805.56
	2	512.10	994.45	1466.23	1531.12	1484.61	1453.60	1376.07	1298.55	1143.50	678.35
100	1	639.31	1121.66	1593.44	2529.51	3142.49	3111.48	3033.95	2956.43	2801.32	2336.23
	2	512.10	994.45	1466.23	2402.30	3015.28	2984.27	2906.74	2829.22	2674.11	2209.02
200	1	639.31	1121.66	1593.44	2529.51	3869.81	4753.81	5966.68	5889.16	5734.11	5628.96
	2	512.10	994.45	1466.23	2402.30	3742.00	4626.60	5839.47	5761.95	5606.90	5141.74
300	1	639.31	1121.66	1593.44	2529.51	3869.81	4753.81	6963.81	8821.88	8666.83	8201.68
	2	512.10	994.45	1466.23	2402.30	3742.60	4626.60	6836.60	8694.67	8539.62	8074.47
400	1	639.31	1121.66	1593.44	2529.51	3869.81	4753.81	6963.81	9173.81	11599.56	11134.41
	2	512.10	994.45	1466.23	2402.30	3742.00	4626.60	6836.60	9046.60	11472.35	11007.20
800	1	639.31	1121.66	1593.44	2529.51	3869.81	4753.81	6963.81	9173.81	11599.56	11134.41
	2	512.10	994.45	1466.23	2402.30	3742.60	4626.60	6836.60	9046.60	13466.60	22738.10

Within the land and water constraints of the pump system the estimated maximum returns to labor and management were N11600 (N6.42/hour) for a single pump user and N23000 (N12.74/hour) for the two pumps user. The returns associated with the maximum available water of 200 ha-cm used by the pump farmers irrigating 1.5 hectares was N5967 (N3.30/hour). The single pump system is the most profitable at this limiting water level. The pump user with an average water use of 100 ha-cm and about .8 hectare of land have an estimated return to labor and management of N3142 (N1.74/hour). Irrigating the same hectare of land with 200 ha-cm of water would have earned a higher return of N3870 (N2.14/hour), a marginal return of 40 K/hour.

Comparison of the returns to labor and management between the pump and shadoof users within land and water limitations is shown in Figures 5.2 and 5.3. The result indicates that none of the systems are profitable when the water available in the area is constrained to 10 ha-cm or less since the opportunity cost of labor is higher than its return in irrigation farming. The shadoof system has higher returns than the pumping system if the water available is less than 50 ha-cm as is evident in Figure 5.3. With greater than 50 ha-cm of water available, use of a pump is more profitable. If land available is limited to .5 hectare, pumping more than 100 ha-cm of water will not increase the returns to labor and management but rather involve unnecessary pumping cost.

These facts indicate that with an adequate supply of water, the farmers using any of these lift devices can earn a profit under the prices used in this model. However, the water was limited and only an average of 10 ha-cm of water was used on shadoof farms.

Returns to Varying Land and Labor with the Amount of Water Unchanged

Various levels of labor and land resources were specified in this experiment with the model assuming 500 ha-cm of water is available. The maximum amount of water the pump can deliver in a season is 400 ha-cm. The estimated net returns and the marginal contribution of full-time family worker are presented in Tables 5.7 and 5.8 for shadoof and pump farms, respectively.

In case of the shadoof the highest contribution a second full-time family worker could make to the net returns was N164.68 and N152.11 was the highest possible contribution of a third fulltime worker on a .3 hectare of land. These marginal contributions are lower than the seasonal labor opportunity cost of N230.51 since these workers could work elsewhere for this amount on a fulltime basis.

The use of an additional full-time family worker did not quite substitute for hired labor when it was needed (Table 5.9). In the case of the first man added, he contributed 663.62 hours but replaced 448.4 hours of hired labor. He was about 73 percent employed. In the case of the second man added, he contributed 756 hours but replaced only 2.85 hours of hired labor. He was about 84 percent employed.

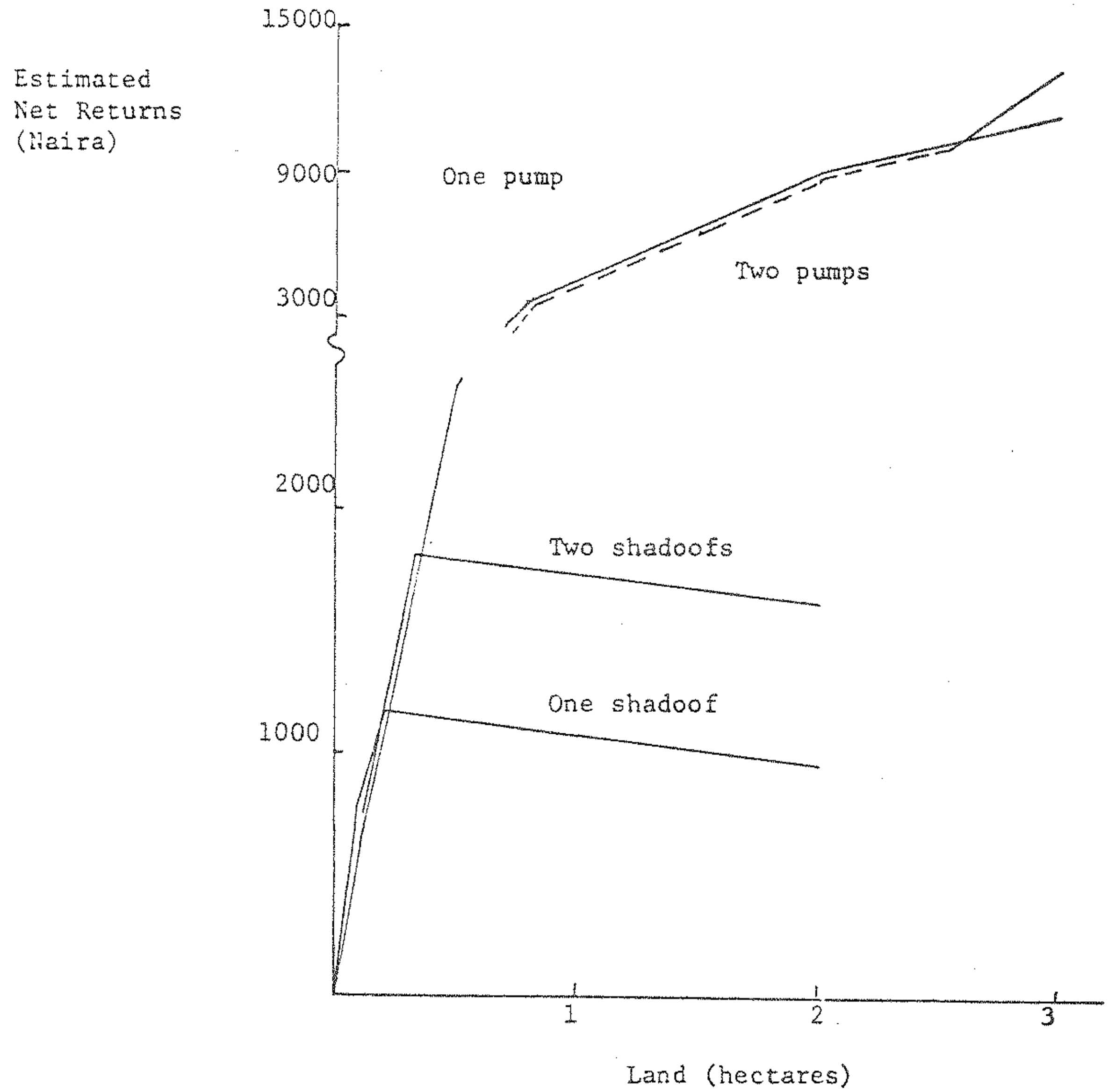


Figure 5.2. Estimated Net Returns to Labor and Management at Various Hectares of Land Irrigated.

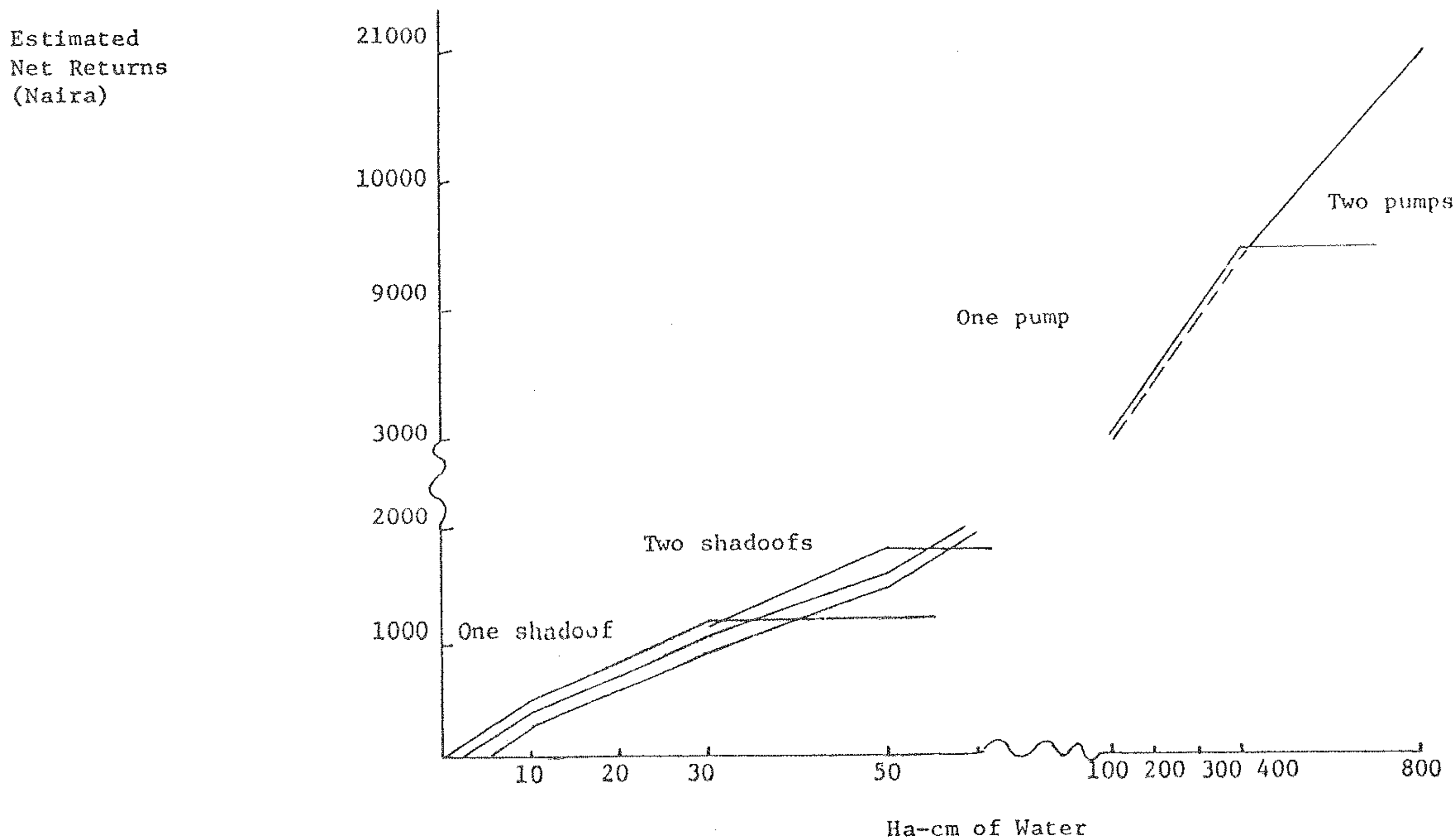


Figure 5.3. Estimated Net Returns to Labor and Management at Various Ha-cm of Water Used.

Table 5.7. The Returns to Labor and Management Related to Various Levels of Land and Labor under the Shadoof Lift System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Land Area Irrigated (ha.)	Full-Time Family Worker (No.)	Returns to Labor and Management: Net Returns (N)	Returns to Labor and Management: Marginal Contributions (N)
.1	1	623.68	623.68
	2	765.88	142.20
	3	880.88	115.00
.2	1	1098.63	1098.63
	2	1252.26	153.63
	3	1395.49	143.23
.3	1	1559.15	1559.15
	2	1723.83	164.68
	3	1875.94	152.11

N = Naira

Table 5.8. The Returns to Labor and Management Related to Various Levels of Land and Labor with 500 Ha-cm of Water under the Pump System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Land Area Irrigated (Ha.)	Full-Time Family Worker (No.)	Returns to Labor and Management: Net Returns (N)	Returns to Labor and Management: Marginal Contribution (N)
.1	1	497.22	497.22
	2	639.31	142.09
	3	754.42	115.11
.2	1	968.03	968.03
	2	1121.66	153.63
	3	1264.89	143.23
.3	1	1429.30	1429.30
	2	1593.44	164.14
	3	1746.09	152.65
.5	1	2313.30	2313.30
	2	2529.51	216.21
	3	2690.74	161.23
.8	1	3639.30	3639.30
	2	3869.81	230.51
	3	4090.99	221.18
1	1	4523.30	4523.30
	2	4753.81	230.51
	3	4984.32	224.51
1.5	1	6733.30	6733.30
	2	6963.81	230.51
	3	7194.32	230.51
2	1	8943.30	8943.50
	2	9173.81	230.51
	3	9404.32	230.51
3	1	13236.09	13236.09
	2	13466.60	230.51
	3	13697.11	230.51
6	1	13709.41	13709.41
	2	13939.92	230.51
	3	14170.43	230.51

N = Naira

Table 5.9. Results Obtained from Varying Full-Time Family Workers with .3 Hectare of Land under Shadoof System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Item	Full Time Family Workers		
	1	2	3
Total labor used (hrs.)	2427	2642.21	3395.43
Hired labor (hrs.)	1517.1	1068.686	1065.84
Family labor (hrs.)	909.9	1573.52	2329.587
Hired labor replaced (hrs.)		448.4	2.846
Family labor added (hrs.)		663.62	756.067
Percent employment	100	73	84
Water used (ha-cm)	46.8	52.1	70.34
Crops Grown			
Garden Eggs (kg.)	8297.1	9711.4	11970.6
Onions (kg.)	282.6	1007.2	3543.1
Peppers (kg.)	4118	3596.9	1772.9
Tomatoes (kg.)	16.5	102.7	404.6

With the area of land irrigated unchanged at .3 hectare, the additional family labor utilized in addition to the hired labor was spent on lifting more water (from 46.8 to 70.34 ha-cm) to irrigate more onions, garden eggs and tomatoes and less peppers (Table 5.9). The 70.34 ha-cm of water cannot efficiently be delivered by the shadoof since a two-shadoof system is the least costly method up to 50 ha-cm of water. However, this fact indicates that with a limited amount of land area available, the farmer will substitute water for land, provided there is adequate number of full-time family workers to lift the additional amount of water used in the irrigation of less peppers and more garden eggs, onions and tomatoes.

In the case of the pump farmer, the highest contribution a second full-time family worker could make to the net returns was N216.21 and 161.23 was the highest possible contribution of a third full-time worker on a land area of .5 hectare or less. These contributions are lower than the seasonal labor opportunity cost these workers could earn elsewhere on a full-time basis. The use of additional full-time labor did not quite substitue for hired labor in the case of the second man added (Table 5.10). The first man resulted in an 838 hour reduction in the hired labor. He was about 93 percent employed. The second man contributed 618 hours but replaced 510.4 hours of hired labor. He was about 68 percent employed.

With the area of land irrigated unchanged at .5 hectare, the hours of labor added by the second man, besides replacing some hours of hired labor, was spent on lifting more ha-cm of water (78 to 80.62) for a different proportion of the crop-combination. The new crop-combination is more garden eggs, onions and tomatoes and less peppers.

The average pump farmers irrigating between .8 and 1 hectare might consider the use of an additional full-time family worker since they require at least one fulltime worker besides the operator. The marginal contribution of this worker (N230.51) equals the labor opportunity cost. Farmers irrigating 1.5 hectares or more use at least two full-time workers for which family labor could substitute.

In summary, irrigation farming with a shadoof lift system only needs one full-time family operator and some supplemental hired labor. The average pump farm can employ at least two full-time family members including the operator. If a pump is irrigating less than .5 hectare the operator would need only part-time supplementary labor. In addition, the experiment indicates that with limited land supply and excess family labor hours, farmers will use more water and the excess labor to cultivate water and labor demanding crops. This might suggest that water and labor are complementary inputs.

Table 5.10. Results Obtained from Varying Full-Time Family Workers with .5 Hectare of Land under Pump System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Item	Full-Time Family Workers		
	1	2	3
Total labor used (hrs.)	4045	4045	4152.603
Hired labor (hrs.)	3130.5	2292.5	1782.093
Family labor (hrs.)	914.5	1752.5	2370.51
Hired labor replaced (hrs.)		838	510.407
Family labor added (hrs.)		838	618.01
Percent employment	100	93	68
Water used (ha-cm)	78	78	80.62
Crops Grown			
Garden eggs (kg.)	13828.5	13828.5	14236.7
Onions (kg.)	471	471	833.3
Peppers (kg.)	6863.5	6863.5	6602.9
Tomatoes (kg.)	27.5	27.5	70.6

Returns to Varying Water and Labor with the Amount of Land Unchanged

This experiment with the model assumes six hectares of land are available. This was the maximum that any pump farmer reported he could use. The estimated marginal returns to labor and management are presented in Tables 5.11 and 5.12 for shadoof and pump farms, respectively.

With a water constraint on the shadoof system, the use of two full-time family workers earned a maximum return to the second full-time family laborer of N117 for a single shadoof user and N166 for a two-shadoof user. These contributions of an additional fulltime worker are lower than the full season labor opportunity cost (N230.51).

In the case of a single shadoof, the use of an additional full-time family worker did not substitue for hired labor but actually increased the use of hired labor, given if 30 ha-cm of water was available. This first man contributed 689 hours and the hired labor increased by 27.89 hours (Table 5.13). He was about 76 percent employed. The second man contributed 731 hours and the hired labor increased by 259 hours. He was about 81 percent employed.

With the amount of water available constrained at 30 ha-cm, both the full-time family worker and the hired labor worked on farming reduced hectares of land (.192 to .178) and different proportions of the crops grown. The proportions of the crops in the combination changed to more onions, garden eggs and tomatoes but less peppers (Table 5.13). This fact indicates that with water constrained at a given level farmers will substitute labor for land to take advantage of the amount of water available. That garden eggs, onions and tomatoes are labor intensive with peppers being land intensive is also reflected in the result.

For a two-shadoof system, with 50 ha-cm of water, the addition of one full-time family worker substituted for hired labor when it is needed, but when a second full-time family worker was added it increased the hours of hired labor. The first man added was 68 percent employed with the second man 78 percent employed.

With the first man added substituting for hired labor, the field operations and the proportion of crops in the combination grown was unchanged. However, with a second man added, labor was substituted for land and the proportion of the crops in the combination changed to more onions, garden eggs and tomatoes but less peppers. Therefore, with the contribution of an additional family member is less than his full season labor opportunity cost, the availability of excess labor hours results in the reorganization of the planting strategy to include the growing of more labor intensive crops and less land intensive crops. With land constrained, the farmers substituted water to the extent possible.

The pump system farm can use the services of two full-time family workers, if the amount of water available is at least 100 ha-cm and three full-time family laborers for water availability of 200 or more ha-cm. However, for water constraints of 50 ha-cm or less, use of more than one full-time family worker in addition to the operator will not return a full season's wage. The additional full-time worker would

Table 5.11. The Returns to Labor and Management Related to Various Levels of Water and Labor under the Shadoof Lift System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Water Used (ha-cm)	Full-Time Family Worker (No.)	Returns to Labor and Management: Net Returns (N)	Returns to Labor and Management: Marginal Contribution (N)
2	1	114.21	0
	2	114.21	0
	3	114.21	0
10	1	424.24	424.24
	2	521.23	96.99
	3	590.74	69.51
20	1	749.59	749.59
	2	853.36	103.77
	3	953.96	100.60
30	1	1062.48	1062.48
	2	1179.50	117.02
	3	1282.49	112.17
50	1	1650.54	1650.54
	2	1816.80	166.26
	3	1928.97	112.70

N = Naira

Table 5.12. The Returns to Labor and Management Related to Various Levels of Water and Labor under the Pump System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Water Used	Full-Time Family Worker	Returns to Labor and Management	
		Net Returns	Marginal Contribution
(ha-cm)	(no).	(N)	(N)
10	1	299.27	
	2	396.26	96.99
	3	465.77	69.51
20	1	621.97	
	2	725.74	103.77
	3	826.34	100.60
30	1	932.21	
	2	1049.23	117.02
	3	1152.22	102.99
50	1	1519.83	
	2	1686.09	166.26
	3	1798.26	112.17
100	1	2936.63	
	2	3167.14	230.51
	3	3349.78	182.64
200	1	5769.98	
	2	6000.49	230.51
	3	6231.00	230.51
300	1	8603.31	
	2	8833.82	230.51
	3	9064.33	230.51
400	1	11436.63	
	2	11667.15	230.51
	3	11897.66	230.51
500	1	22642.79	
	2	22873.30	230.51
	3	23103.81	230.51

N = Naira

Table 5.13. Results Obtained from Varying Full-Time Family Workers with 30 Ha-cm of Water under the Shadoof System, Ringim LGA, Kano, Nigeria, 1978/79 Irrigation Season.

Item	Full-Time Family Workers		
	1	2	3
Total labor used (hrs.)	1555.77	2273.155	3262.411
Hired labor (hrs.)	744.116	772.008	1030.831
Family labor (hrs.)	811.654	1500.657	2231.58
Hired labor added (hrs.)		27.89	258.823
Family labor added (hrs.)		689.338	730.921
Percent employment	90	76	81
Land area (ha.)	.192	.186	.178
Crops Grown			
Garden eggs (kg.)	5318.7	7912.	11488.1
Onions (kg.)	181.2	334	544.9
Peppers (kg.)	2639.8	1978.1	1065.6
Tomatoes (kg.)	10.6	547.2	1287.3

substitute for supplemental labor which would not have to be full-time.

This experiment indicates that the decision of which crops to grow is based upon the perception of the farmer concerning how much water would be available under relative crop prices used in this model. However, the decision about the relative proportion of each crop in the combination depends on the number of full-time family workers available and the cost of hired labor. If the added full-time family labor totally substitutes for hired labor when needed, the proportion of crops in the combination is unchanged, otherwise the family will grow more labor and water intensive crops (garden eggs, onions and tomatoes) and less of the land intensive crop (peppers) under price assumptions used in this model.

The Impact of Pump Breakdown, Repairs and Pumping Cost

One of the farmers who was irrigating .614 hectare of land had his pump break down at the start of the season. Subsequently, he irrigated his field using a two-shadoof system. The return to labor and management from the shadoof system was N1783.50 and that from the pump would have been N3038.83. The opportunity loss to the farmer in using the shadoof system instead of the pump was N1255.33 or 49 percent of pump earnings. This opportunity loss is compounded for farmers irrigating larger areas of land since the returns to the shadoof system diminishes after .32 hectares of land due to its water delivering constraints.

Similarly, ten other farmers experienced a break down (Chapter III). Unlike this farmer, eight of the ten farmers took the system to the servicing station in Kano for repairs, a journey of 156 kilometers. The other two reported doing nothing. The opportunity loss for the two farmers that did nothing was the full returns to their pump farms or the returns to the pump farms excluding returns to other employment they may have secured. The journey of 156 kilometers for those farmers who took the pump for servicing was very tiring. Moreover, repeated breakdowns during the season are possible.

The above experience illustrates two important problems: (1) the risk and uncertainty associated with a pump breakdown and repairs, and (2) the use of shadoof in case of pump breakdown to help minimize the opportunity loss.

Another option for minimizing loss and reducing risk and uncertainty the farmer irrigating with a pump could consider is the purchase of two pumps. The average total cost per ha-cm of water for operating the two-pump system is not greatly different to the single pump system in delivering 100 ha-cm or more of water (Figure 5.1). The net returns to labor and management of the two-pump system is almost the same as that of a single pump system for a land area of 2.564 hectares or less and greater returns for larger areas as evident in Figure 5.3 and Table 5.6. Furthermore, owning two pumps reduces the probability of being without a pump system during the irrigating season and also saves time of delivering the needed amount of irrigation water.

It would therefore appear that owning two pumps would be advantageous. However, the farmers indicated that it was difficult to obtain the capital needed to buy pumps. Also, the pumps are not always available for purchase according to the reports of 67 percent of the farmers.

In order to ascertain the impact of the pumping costs on the use of pumps as a lift device, a 100 percent increase in the fuel, repairs and maintenance costs were assumed. This meant that the variable cost per ha-cm of water excluding attendance labor was doubled from 83 Kobo to N1.66 (Table 5.1). In delivering water of more than 51 ha-cm the increase in pumping costs have no perceptible influence. However, doubling the fixed cost of the pump (similar to buying two pumps) show that three and four shadoof systems will be the least costly method for delivering water of 90 ha-cm or less.

Impact of the Wage Rate

The 1978/79 and 1981/82 hourly wage rates (Table 4.13) were specified in this experiment with two full-time family workers, 500 ha-cm of water and ten levels of hectares of land (.1, .2, .3, .5, .8, 1, 1.5, 2, 3, 6). (The 1978/79 hourly wage rates were used in all the earlier experiments presented in Tables 5.2, 5.3, and 5.4.)

In the case of 1978/79, the estimated average amount of water used on one hectare was 156 ha-cm with 1855 hours of lift labor for the shadoof system and 185.5 hours for the pump system. With the 1981/82 wage rate, the estimated amount of water was 140.2 ha-cm with 1228.8 hours of lift labor for shadoof and 122.9 hours for pump attendance labor. Using the 1981/82 estimates the average total cost per ha-cm of water was computed as presented in Table 5.14.

These data are plotted in Figure 5.4. For lifting volumes of water between 1 and 34 ha-cm, the shadoof is the least cost method, beyond which the pump is the most economical. Adding a second shadoof is economical only between 30 and 32 ha-cm. The pump system is least costly for lifting more than 32 ha-cm of water. The maximum land area that would be irrigated by shadoof is .228 hectare as compared to .32 hectare at the lower wage rate (1978/79). The higher wage rate (1981/82) results in (1) decreasing the use of water from 156 to 140.2 ha-cm per hectare, (2) elimination of a two-shadoof system. The pump system became the least costly method (substitution of capital for labor) and (3) should the two-shadoof system be used, the maximum land area over which it could efficiently be used was reduced from .32 to .228 hectare.

Another effect of the wage increase experiment was the change in crops combination. At the low wage rate, the dominant crops in the combination were garden eggs and peppers. Increasing the land area irrigated only increased the magnitude of the quantity of the crops in the combination but not the relative importance. Under the higher wage rate, the proportion of the crops in the combination changes with pepper being the dominant crop. At 5.26 hectares of land only pepper with traces of the other crops was optimum. This occurs because as labor becomes expensive farmers

Table 5.14. The Average Total Cost of Lifting Water with the Irrigation Systems, Based on 1981/82 Wage Rate, Ringim LGA, Kano, Nigeria.

Volume of Water Lifted (ha-cm)	Average Total Cost of Lifting Water: One Shadoof (N)	Two Shadoofs (N)	One Pump (N)
2	7.46	9.91	64.94
5	5.99	6.97	26.77
10	5.50	5.99	14.05
20	5.26	5.51	7.69
30	5.17	5.33	5.57
40	5.13	5.25	4.51
50	5.11	5.21	3.87
60	5.09	5.17	3.45

N = Naira

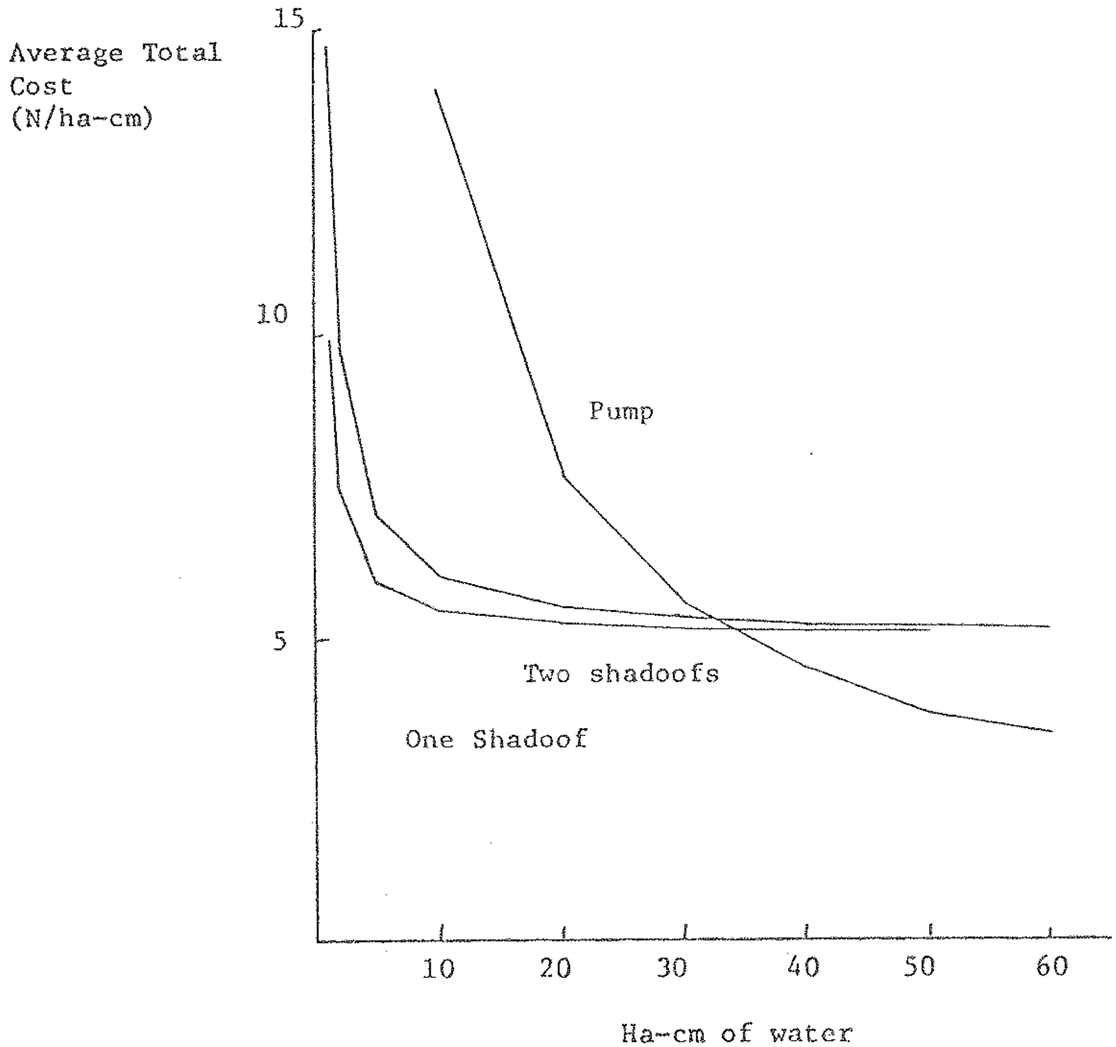


Figure 5.4. Relationship between Average Total Cost per Ha-cm and Volume of Water Lifted Using 1981/82 Labor Cost.

will switch from growing high labor use crops (onions, garden eggs, and tomatoes) to land intensive crops (peppers) with product prices unchanged. Also as the land area irrigated increases, less water and labor are used on a per hectare basis.

With 500 ha-cm of water specified, the maximum land area irrigated at the low wage was 3.26 hectares and 5.26 hectares at the high wage rate. The quantity of the crops produced on the 3.26 hectares were 88644.2 kg. of garden eggs, 3019.2 kg. of onions, 43996.8 kg. of peppers and 176.3 kg. of tomatoes utilizing 25929.5 hours of labor. The quantity produced on the 5.26 hectares were 1378.9 kg. of garden eggs, 1705.3 kg. of onions, 49636.8 kg. of peppers and 100 kg. of tomatoes utilizing 5626.3 hours of labor. This substitution or change reflects the fact that peppers use more land and less labor and water. The returns to labor and management at the high wage rate was N11874.23.

Government Policy Considerations

Nigeria, concerned with the declining role of agriculture to the GDP, increasing food imports and unemployment, might consider as a government policy the promotion of these small scale irrigation farming devices, since the returns to additional water in the area is quite high. The facts presented in this chapter indicate that with an adequate water supply, irrigation farming with these lift devices earns a profit and could be a source of employment under the prices used in the model.

However, the water was limited and only an average of ha-cm of water was used on shadoof farms and 100 ha-cm on pump farms. Promotion of borehole construction that can deliver at least 150 ha-cm of water might be considered as a government policy based on economic optimum of the model. There is an adequate supply of ground water (Figure 1.1).

Other problems of concern to the farmers include the availability of the pumps and the capital to purchase them, and the repairs and maintenance difficulties. Efforts by the government to provide a dependable credit system, making the pumps and associated repair facilities available could eliminate some of the shadoof and pump lift irrigation farming problems. Government policy-makers interested in increasing agricultural output might find the benefit-cost ratios of these techniques high enough to be competitive when compared with other projects and policies.

However, there is a microeconomic problem of elasticity of demand for the product and elasticity of demand for the inputs. The impact of an improved technology or adoption of a technology is to make it possible for producers to supply the same amount at a lower cost and thereby sell at a lower price or supply more at the same price. Aggregate supply then increases. If the consumer possesses an inelastic demand curve for that food (with increased supply), producers receive less total revenue. If demand is elastic, they receive more total revenue and if the elasticity is unitary the total revenue is unchanged.

Further, in agriculture, demand curves are most often inelastic so less total expenditure will be required to obtain this total product [35]. Thus, given an inelastic demand curve, total value of farm production will fall under improved technology or if more farms adopt the shadoof and pump irrigation systems. No data is available in this research to analyze this problem. It is an area that needs to be studied if small scale irrigation technology is to be promoted.

SUMMARY AND CONCLUSIONS

The current drought in Northern Nigeria, the declining contribution of agriculture to the GDP, increasing food imports and the need for agriculture to play a greater role in the socio-economic development of the country have intensified interest in irrigation development in Nigeria. Although the trend of irrigation development has been mainly directed towards large scale irrigation, this research was designed to study the small scale lift irrigation methods of applying water (shadoof and pump). These lift systems are used by the farmers in most arid and semi-arid regions of Nigeria.

It was hypothesized that promotion and improvement of these systems might contribute to more efficient agricultural production. This study was, therefore, designed to estimate the economic returns to small scale shadoof and pump irrigation systems and to indicate implications of these returns for research, extension, and government policy.

The analytical framework chosen for this analysis was a linear programming model. One of the problems of using the model was that the farmers intercropped. Intercropping (several crops intersown on the same field) makes it difficult to directly relate factors, i.e., variable inputs (land, labor, water) used in the production of a specific crop. Regression analysis permitted identification of the effect of the variable inputs on production of each crop. The regression results were used in the specification of small scale irrigation linear programming activities. This model was called the Production Possibility-Convex Approximation Model (PP-CAM). The objective function of the PP-CAM involved the maximization of expected net income subject to resource use constraints. The constraints were land, labor, and water resources.

The data necessary to estimate the coefficients or parameters of the model were obtained from 114 irrigation farmers in Ringim LGA, Kano, Nigeria. These were interviewed each week during the 1978/79 irrigation season. Of the 114 farmers interviewed, 104 used a shadoof lift system and 10 used motor driven pumps.

The average capital investment for the irrigation systems was N688 for pumps and N16 for the shadoof. Shadoof farmers constructed their shadoofs from materials available on their farm, but the imported pumps were purchased from sales outlets in cities. The average fixed costs were N127 for the pumps and N5 for the shadoof system. The average operating costs per ha-cm of water delivered to the field were N3.46 for the shadoof and N1.17 for the pump in 1978/79. Most of the operating cost for the shadoof was for labor to lift the water. For the pump system, most of the operating cost was for fuel.

Several experiments using various levels of water, land, and labor were made with the model. At 1978/79 prices and wages the results indicate that for lifting volumes of water between 1 and 51 ha-cm the shadoof is the least-cost system. When the volume of water required exceeds 51 ha-cm the pump is the least-cost device. However, the physical capacity of a single shadoof is limited to 30 ha-cm and two shadoofs are required to deliver between 30 and 50 ha-cm of water. The pump system with maximum pumping capacity of 750 liters per minute, if used throughout the 903 hours available in the season, would deliver 400 ha-cm of water. To deliver more than 400 ha-cm of water to the farm requires at least two pumps.

Experiments with the model were designed using 1978/79 prices, wages for hired labor and the average family labor (two full-time family workers) to ascertain the land area that maximizes returns given the water delivering limitations of the lift system. The results indicate that a single shadoof with a 30 ha-cm water limitation maximizes return by irrigating .192 hectare and a two-shadoof system maximizes return when .32 hectare is irrigated. The pump with a 400 ha-cm water limitation maximizes return at 2.564 hectares. Additional pumps are required to maximize returns when irrigating land areas greater than 2.564 hectares.

Under these conditions, experiments were conducted to estimate the returns to labor and management. The estimated returns to labor and management were N1179 for a single shadoof, N1728 for a two-shadoof user and N11600 for a single pump user.

Since the maximum water usage reported by farmers was about 200 ha-cm and land irrigated about 1.5, these figures were set as constraints with other conditions as above. The returns to family labor and management amounted to N5967 which was more than the two family workers could have earned as hired labor. Similarly, 10 ha-cm was tried since this was the average for the shadoof farmers. The result indicated that none of the lift systems could pay the two family workers equivalent to the hired wage rate under this condition.

The average water used by pump farmers was 100 ha-cm. Under the experimental conditions previously described, the maximum return to labor and management was N3142.49. The maximum return for the single shadoof and two shadoofs at the 10 ha-cm rate per shadoof was N517.13 and N512.24, respectively. This implies that the average pump user earned more than the wage rate and the average shadoof user earned less than the hired wage rate.

In order to ascertain how many full-time family workers are required to operate the farms using these irrigation systems, experiments with the model were made using .2 hectare of land (the average for shadoof systems), .8 hectare of land (average pump farm size), and unconstrained amounts of water. The results indicated that irrigation farming with shadoofs required only one full-time family operator and part of one supplementary hired laborer to maximize returns per family worker. The marginal contribution of additional family labor is lower than the full season labor opportunity cost of N230.51. The average pump farm can employ at least two full-time family members including the operator and still compensate them at the hired wage rate. However, the combination of operator and part of hired laborer maximizes returns to the operator.

In the model with land constrained at .2 hectare, the average shadoof irrigated area, labor and water were substituted for land. Labor and water were complementary inputs because as the use of one increased, the other increased. With two or more full-time family workers and water unconstrained, relatively labor and water intensive crops (garden eggs, onions and tomatoes) were substituted for the most land intensive crop (peppers).

If the capital investment of the pump doubles and increases fixed cost, three and four shadoof systems become the least-cost method between 50 and 90 ha-cm of water lifted. However, doubling of the variable costs of pumping has no perceptible influence on the levels at which the pump becomes the least-cost method. However, using the 1981/82 wage rate which is about 97 percent higher than the 1978/79 rate, the pump system becomes the least cost method of lifting at a lower level of water lifted. In fact, it replaced the two-shadoof system over the range for which that system was the least-cost method at the 1978/79 wage rate. The two-shadoof system was practically eliminated since it became least costly only for the range 30 to 32 ha-cm of water lifted. This implies the substitution of capital for labor.

In a maximization of return context the increased wage rate led to a decreased use of water and a switch from the labor intensive crops of garden eggs, onions and tomatoes to the relatively more land intensive peppers.

Implications and Government Policy

Expansion of Irrigated Land Area

The farmers indicated that land and labor were available for additional crop production during the dry season. These factors were not limiting the expansion of irrigation farming.

The pump farmers reported the availability of six hectares of land but were irrigating an average of .8 with a maximum of 1.5 hectares. The model indicated that a pump farmer irrigating .8 hectare with unlimited water would maximize returns with two full-time family workers including the operator unless the family labor were valued at less than the going hiring wage. However, three fulltime family workers including the operator was the average family labor used.

The shadoof farmers had available about two hectares but only irrigated an average of .2 hectare. The model indicated that a shadoof farmer irrigating .2 hectare with unlimited water would maximize returns per family worker with one full-time family operator. Further, a second full-time worker could not contribute the value of the hired wage rate.

Nevertheless, the average shadoof farmer reported having two full-time family workers including the operator. These farmers had excess labor for the amount of land irrigated even with water unconstrained. Since they reported more land available, lack of water probably is the main factor that keeps them from fully employing their labor.

The shadoof farmers used an average of only 10 ha-cm of water and the pump farmers used 100 ha-cm instead of the unlimited amount in this experiment. The model indicated that none of the systems could remunerate the operator with the current wage (1978/79) when the water available in the area is constrained to 10 ha-cm or less. The average shadoof farmer was not earning the 1978/79 hired wage rate by irrigating.

Other problems cited by the farmers included lack of capital or credit. This factor would only inhibit the expansion of irrigated land are if it limited the development of new water supplies. Very little capital is required to expand irrigated land area if a shadoof is used since the water lift device can be constructed by the farmers from materials available at little or no cost in the area. Other inputs, such as fertilizer, chemicals and improved seeds were not considered to be obstacles to irrigation expansion.

If the government desires to encourage the development of more irrigated land area they could concentrate efforts on aiding the farmers to develop shallow wells, ponds, boreholes and stable water supplies. Ground water itself is not limiting in this and many other arid or semi-arid areas in Nigeria. Farmers would expand irrigation with either the shadoof or pump lift devices if they have a dependable supply of water. The analysis of this study indicated that the returns to additional water in the area are quite high. The average shadoof farmer was not obtaining a return equal to the hired wage rate due to lack of sufficient water supply.

Adoption of the Pump Technology

Although the estimated returns to the pump are substantial, its use requires substitution of capital for labor. However, nearly all the shadoof farmers reported the high investment cost of a pump as the factor which limited their adoption of the device even though 73 percent of the farmers preferred the pump to the shadoof.

Furthermore, the pumps are not reliable and repairs are difficult and costly to obtain. In order to avoid the danger of a complete loss of the crop from a pump breakdown, a shadoof backup system would need to be maintained. The analysis of the cost of lifting water indicated that use of a two-pump system could also be used to reduce crop loss with very little increase in the cost of water lifted.

A policy designed to make capital available for increased pump investment could increase national food output substantially since there are thousands of farmers who could increase their scale of irrigation farming substantially if they had pumps. The increase in food productivity would occur as the labor released from shadoof operations with the adoption of pumps was used to expand the area under irrigation. Subsidization of the pumps might not be necessary since the pump system operating at full capacity appears capable of repaying costs and earning a profit given a reasonable infrastructure to maintain the pumps. However, a loan might be needed initially to purchase a pump to develop the cash flow to repay the government for the investment.

Benefit-cost analysis of these technologies may be competitive when compared with those of other projects and policies. This research indicates that the benefits from promoting these small scale lift devices are worthy of consideration by policymakers interested in increasing agricultural output. However, this research did not examine the aggregate impact on crop prices that would result from major increases in the production of these crops.

Suggestions for Further Research

In this study, the high returns from irrigation farming with these lift systems depended upon price conditions such as occurred in 1978/79. If adoption of these technologies were increased through water and/or the capital supply policies considered above, the increased supply of the products might lower prices. If an inelastic demand exists for the products involved, the producers could receive less total revenue. Research into this situation should preceed adoption of any policies promoting any large scale plans to increase production through use of these lift devices.

Secondly, with water identified as a barrier to expansion of irrigated area, the cost of constructing boreholes, shallow wells, and ponds becomes important. Research to examine the cost feasibility of borehole construction and/or other suitable ways of making irrigation water available for this type of irrigation farming would also be needed.

BIBLIOGRAPHY

1. Abalu, George O. I., "A Note on Crop Mixtures under Indigenous Conditions in Northern Nigeria," Journal of Development Studies, Vol. 12, No. 3, April 1976, pp. 212-220.

2. Abalu, George O. I. and B. D'Silva, "Nigeria's Food Situation: Problems and Prospects," Food Policy, February 1980, pp. 49-60.

3. Abalu, George O. I. and B. D'Silva, "Socioeconomic Analysis of Existing Farming Systems and Practices in Northern Nigeria," Paper presented at the Workshop on Socioeconomic Constraints to the Development of Semi-Arid Tropical Agriculture, ICRISAT, February 19-23, 1979, 14 p.

4. Agrawal, R. C. and Earl O. Heady, Operations Research Methods for Agricultural Decisions, Iowa State University Press, 1972, 303 p.

5. Akande, Oyeniyi, "Proceedings of the First Nigeria Irrigation Seminar," Ahmadu Bello University, Zaria, Nigeria, May 10-12, 1971.

6. Akande, Oyeniyi, "Proceedings of the Third Nigeria Irrigation Seminar," Ahmadu Bellow University, Zaria, Nigeria, August 13-18, 1973.

7. Ansell, Allison, "Small Scale Water Storage and Irrigation: An Economic Assessment for Southwest Nigeria," Department of Agricultural Economics and Management, University of Reading, England, Development Study No. 17, 1979, 88 p.

8. Baba, Jacob Mundi, "Induced Agricultural Change in a Densely Populated District: A Study of the Existing Agricultural System in Kura District and the Projected Impact of the Kano River Irrigation Project, Kano State, Nigeria," Ph.D. Thesis, Ahamdu Bello University, 1975.

9. Balcet, Jean-Claude and Wilfred Chandler, "Farm Technology Adoption in Northern Nigeria," Vol. 1, Report was undertaken under World Bank Research Project RPD 671-88, Commissioned by the Department of Western Africa Projects, Agricultural Division 1 (WAPA1), August 1981.

10. Barnett, Douglas, "Farmers' Goals and Objectives and the Effect of the Goals on the Cultivation of Crops in Sine Saloum, Senegal," M.S. Thesis, Purdue University, 1979.

11. Brown, Dewey, "Prospects for Minor Irrigation in Northern Nigeria," USAID, Consultant Report No. 23, April 11, 1961, 16 p.

12. Burke, Victor, Memo, April 18, 1981, WAPA1, World Bank.

13. Chambers, R., "The Socio-Economics of Perspective Technologies," Presented at the Workshop on Socio-Economic Constraints to Development of Semi-Arid Tropical Agriculture, ICRISAT, India, February 19-23, 1979.

14. Cohen, Stan A., "An Economic Analysis of Millet Production in Two Dogon Villages in Mali, West Africa," M.S. Thesis, Purdue University, August 1981.

15. Collinson, M. P., Farm Management in Peasant Agriculture, New York: Praeger, 1972.

16. Crawford, Eric W., "Understanding, Quantification, and Modelling in Farming Systems Research: Results of a Simulation Study in Northern Nigeria," Ag. Econ. Staff Paper No. 80-19, Department of Agricultural Economics, Michigan State University, March 1980.

17. Dalrymple, Dana G., "Survey of Multiple Cropping in Less Developed Nations," Foreign Agricultural Economics Report, No. 91, USDA, ERS, 1971.

18. Erhabor, Patrick O.,"Micro-Economic Analysis of Small Scale Irrigation System in Nigeria: A Case Study of Shadoof and Pump in Ringim LGA, Kano State," A Research Proposal, Department of Agricultural Economics and Rural Sociology, IAR/ABU, PMB 1004, Zaria, Nigeria, January 1978.

19. Erhabor Patrick and William Miller, "The Adoption of Small Scale Irrigation Technologies in Nigeria," Department of Agricultural Economics, Purdue University, West Lafayette, Indiana. Submitted to Food Policy, 1981, 20 p.

20. Evans, A. C., "Studies of Intercropping: 1. Maize or Sorghum with Groundnuts," East African Agriculture and Forestry Journal, Vol. XXVI, No. 1, July 1960, pp. 1-10.

21. FAO, Agricultural Development in Nigeria, 1965-80, Rome 1965.

22. Goodwin, J. B., "Description of the Farm Family Linear Programming Model of the Wolof," Draft, 1979.

23. Heady, Earl O., "Synthesis of Decision and Planning Tools and Environment," in Earl O. Heady, ed., Economic Models and Quantitative Methods for Decisions and Planning in Agriculture: Proceedings of an East-West Seminar, Iowa State University Press, pp. 7-28, 1971.

24. Herath, H. M. Gamini, "Crop Mixture under Peasant Conditions: A Decision Theoretic Interpretation," Journal of Development Studies, Vol. 16, No. 3, April 1980, pp. 322-331.

25. Heyer, J., "A Linear Programming Analysis of Constraints on Peasant Farms in Kenya," Food Research Institute Studies on Agricultural Economics, Trade and Development (Stanford University).

26. Hopkins, Elizabeth, "Wolof Farmers in Senegal: A Study of Responses to an Agricultural Extension Scheme," Ph.D. Thesis, University of Sussex, July 1975.

27. Hopper, H. David, "Allocation Efficiency in a Traditional Indian Agriculture," Journal of Farm Economics, Vol. 47, No. 3, August 1965, pp. 611-624.

28. Idachaba, Francis Sulemanu, "Agricultural Research Policy in Nigeria," Research Report No. 17, International Food Policy Research Institute, August 1980, 70 p.

29. Iqbal, Muhammad, "Irrigation Projects of the Northern States of Nigeria," Vol. 1, IAR/ABUG Zaria, August 3, 1975, 32 p.

30. Lanagran, Kevin and Brian D'Silva, "Nigeria: Foundations for Country Strategic Planning," International Economics Division, Economics and Statistics Service, USDA, Staff Report No. 1-1981, November 4, 1980, 44 p.

31. Matlon, Peter Joseph, "The Size Distribution, Structure and Determinants of Personal Income among Farmers in the North of Nigeria," Ph.D. Thesis, Cornell University, May 1977.

32. Mellor, J. N., "Toward a Theory of Agricultural Development," in H. R. Southwerth and B. F. Johnston, eds., Agricultural Development and Economic Growth, New York, Cornell University Press, 1967.

33. Molenaar, Albert, "Water Lifting Devices for Irrigation," FAO, Agricultural Development Paper No. 60, 1956, 75 p.

34. McCarl, Bruce, "Indonesia Supply Prospects for Food Crops: A Farm Level Linear Programming Analysis of Dry-Land and Wet-Land Food Crop Production in Indonesia," Projects Department, East Asia and Pacific Regional Office, IBRD, Unpublished Paper, February 1980.

35. McCarl, Bruce A., "Will Improved Agricultural Technology Make Producers Rich?," Dept. of Agricultural Economics, Purdue University, West Lafayette, 1981, 23 p.

36. Niang, Abdoulaye, "A Linear Programming Model of a Representative Sahelian Farm, The Cases of the Cotton Zone in Mali and the Peanut Zone in Senegal," Ph.D. Thesis, Purdue Uni-ersity, August, 1980.

37. Nigeria, Federal Ministry of Economic Development, <u>National Development Plan 1962-68</u>, Federal Government Printer, Lagos, 1963.

38. Nigeria, Federal Ministry of Economic Development, <u>Third National Development Plan 1975-80</u>, Vol. 1 and Revised Vol. 2, Federal Government Printer, Lagos, 1975.

39. Nigeria, Federal Ministry of Information, <u>Second National Development Plan 1970-74</u>, Federal Government Printer, Lagos, 1970.

40. Norman, D. W., "An Economic Study of Three Villages in Zaria Province 2. Input-Output Relationships," Mineo Draft, IAR/ABU, 1970.

41. Norman, D. W., "An Economic Survey of Three Villages in Zaria Province," Samara Miscellaneous Paper No. 37, Zaria, 1972.

42. Norman, D. W., "Rationing Mixed Cropping under Indigenous Conditions: The Example of Northern Nigeria," <u>Journal of Development Studies</u>, Vol. 11, No. 1, October 1974, pp. 3-21.

43. Nwa, E. O., "Water Lifting Devices for Small Scale Irrigation," Project AIV/5, Department of Agricultural Engineering, IAR/ABU, Zaria, 1978, 2 p.

44. Obatunbosun, Dupe, "Nigeria Neglected Rural Majority," National Institute of Socio-Economic Research (NISER), Ibadan, Nigeria.

45. Onwuchekwe, Stanley, "Guide to the Principles and Techniques of Field Measurement," Department of Agricultural Economics and Rural Sociology, IAR/ABU, PMB 1044, Zaria, Nigeria, 3 p.

46. Palmer-Jones, R. W., "Irrigation Development and Irrigation Planning in the North of Nigeria," IAR/ABU, PMB 1044, Zaria, Nigeria, June 1977, 68 p.

47. Salihu, Musa, "Notes on Soil Analytical Report, Ringim, LGA," Soil and Water Laboratory, Ministry of Agriculture and Natural Resources, Kano, Nigeria, August 1978, 6 p.

48. Shapiro, Kenneth H., "Efficiency and Modernization in African Agriculture: A Case Study in Geita District, Tanzania," Ph.D. Thesis, Stanford University, 1973.

49. Yotopoulous, Pan A., Allocative Efficiency in Economic Development, Athens: F. Constantindis and C. Mihalas, 1967.

General References

1. Andrews, D. J., "Intercropping with Sorghum in Nigeria," Experimental Agriculture, 8(1972), pp. 139-150.

2. Avidor, Abraham, "Nigeria: Agricultural and Trade Policies," Foreign Agriculture Service, USDA, May 1981, 51 p.

3. Barlow, C., S. Jayasuria, et al., "Measuring the Economic Benefits of New Technologies to Small Rice Farmers," IRRI Research Paper Series No. 28, May 1979, 21 p.

4. Beal, A. M. and J. M. Bohlen, The Diffusion Process, Iowa State Agricultural Experiment Station Special Report 18, 1957.

5. Bhuiyan, Sadiqul I., "Evaluation of Constraints to Efficient Water Utilization in Small Scale Irrigation Schemes in Bangladesh," Department of Irrigation and Water Management, IRRI, Los Banos, Philippines, March 19, 1977, 20 p.

6. Bhuiyan, Sadiqul I., "Irrigation Water Management Research Program at IRRI: An Overview," Paper presented at the Irrigation Water Management Workshop, IRRI, Los Banos, Philippines, March 26-30, 1979, 9 p.

7. Bhuiyan, Sadiqul, I., "Research for Better Design and Improvement of Irrigation Systems for Efficient Management," Paper presented at the Irrigation Water Management Workshop, IRRI, Los Banos, Philippines, March 26-30, 1979, 33 p.

8. Clark, Collins and Margaret Haswell, The Economics of Subsistence Agriculture, MacMillan St. Martin's Press, 4th Edition, 1970, 267 p.

9. Clayton, Eric S., "Economic and Technical Optima in Peasant Agriculture," Journal of Agricultural Economics, Vol. 14, No. 3, May 1961, pp. 337-347.

10. D'Silva, Brian C. and M. Rafique Raza, "Integrated Rural Development in Nigeria: The Funtua Project," Food Policy, November 1980, pp. 282-297.

11. Easter, K. William and Lee R. Martin, "Water Resources Problems in Developing Countries," Economic Development Center, Department of Agricultural and Applied Economics, University of Minnesota, Bulletin No. 3, July 1977, 107 p.

12. Erhabor, Patrick Osaretin, "An Economic Analysis of Resource Substitution with Sprinkler Irrigation Systems in Use in Oregon's Northern Columbia River Basin Counties," M.S. Thesis, Oregon State University, November 1976.

13. Gafsi,Salem and Terry Roe, "Adoption of Unlike High Yielding Wheat Varieties in Tunisia," Staff Paper P77-15, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota, August 1977, 26 p.

14. Grehan, M., "Increasing Food Production in the Developing Countries by Means of Irrigated Agriculture," Prepared for Canadian Water Resources Association Conference, Vancouver, British Colombia, June 1974, 6 p.

15. Griliches, Zvi, "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica, 25:501-522, October 1957.

16. Harmon, Nicholas, "A Survey of Nigeria: The Most African Country," The Economist, January 23-29, 1982.

17. Hayami, Y. and V. W. Ruttan, Agricultural Development: An International Perspective, Baltimore: Johns Hopkins University Press, 1971.

18. Hodgdon, Linwood L., "The Adoption of New Agricultural Inputs and Practices by Indian Farmers," in H. H. Biggs and R. L. Tinner Meier, eds., Small Farmers Agricultural Development Problems, 1974, pp. 69-76.

19. IRRI,"Irrigation and Water Management," Annual Report for 1976, Irrigation and Water Management and Agricultural Economics Departments, pp. 197-217.

20. Kehrberg, Earl W., "Agricultural Production Economics and Quantitative Methods for Solving Resource Allocation Problems of Production," Agricultural Economics 612, Purdue University, W. Lafayette, Indiana, Spring 1980.

21. Konan, Mildred M., "Occupations and Family Patterns among the Hausa in Northern Nigeria," Samaru Miscellaneous Paper No. 52, IAR/ABU, PMB 1044, Zaria, Nigeria.

22. Maier, F., "An Economic Analysis of the Adoption of the Mechanical Cotton Picker," Ph.D. Thesis, University of Chicago, 1969.

23. Mason, Robert George, "Information Source Use in the Adoption Process," Ph.D. Thesis, Stanford University, 1963.

24. Miller, Leonard F., _Agricultural Credit and Finance in Africa_, The Rockefeller Foundation, November 1977.

25. McCarl, Bruce A., _Application of Quantitative Analysis: Mathematical Programming_, Ag. Econ. 652, Purdue University, Fall 1979.

26. McPherson, W. W., _Economic Development of Tropical Agriculture_, University of Florida Press, 1968, 328 p.

27. Niang, A., "Use of a Mathematical Programming Approach in Malian Livestock Sector Policy Analysis," M.S. Thesis, Purdue University, 1979.

28. Nie, Norman, C. Hadlai Hull, _et al._, _Statistcal Package for the Social Sciences (SPSS)_, McGraw-Hill Book Company, Second Edition, 1975.

29. Norman, D. W., "Data Collection in Farm Management Studies: The Case of Northern Nigeria," Invited paper produced for a Workshop on Field Collection of Socio-Economic Data in Developing Countries, Beruit, Lebanon, December 8-14, 1974.

30. Norman, D. W., "Influence of Location on Land and Labor Relationship in Three Zaria Villages," Rural Economic Research Unit, IAR/ABU, 1967, 16 p.

31. Norman, D. W., "Initiating Change in Traditional Agriculture," IAR/ABU, PMB 1044, Zaria, Nigeria, Samaru Research Bulletin 174, 1973, 14 p.

32. Norman, D. W., "Methodology and Problems of Farm Management Investigations: Experiences from Northern Nigeria," Samaru Research Bulletin 195, IAR/ABU, PMB 1044, Zaria, Nigeria, 1973.

33. Palmer-Jones, R. W., "Agricultural Water Use," Invited paper presented at UN ECWA Seminar on Technology Transfer and Change in the Arab Middle East, Beruit, Lebanon, October 9-14, 1977, 28 p.

34. Palmer-Jones, R. W., "Field Research Methods Used in Farm Management Studies: A Critique of Some Methods Used to Study the Impact of the Kano River Project Pilot Project at Kadawa on Small Farmers," Draft, Department of Agricultural Economics and Rural Sociology, IAR/ABU, Zaria, Nigeria, August 1977, 43 p.

35. Palmer-Jones, R. W., "Linear Programming and the Study of Peasant Farming-Rejoinder," Journal of Agricultural Economics, Vol. 29, 1978, pp. 199-203.

36. Palmer-Jones, R. W., "Peasant Differentiation in Rural Hausaland," Draft, Department of Agricultural Economics and Rural Sociology, IAR/ABU, PMB 1044, Zaria, Nigeria, April 1978, 33 p.

37. Palmer-Jones, R. W., "The Impact of Large Scale Irrigation on Small Farmers at the Kano River Project, Kadawa," Progress Report for the Irrigation Cropping Scheme, IAR/ABU, Zaria, Nigeria, July 1977, 12 p.

38. Patrick, George F., et al., "Small-Farm Agriculture: Studies in Developing Nations," Station Bulletin No. 101, Department of Agricultural Economics, Agricultural Experiment Station, Purdue University, West Lafayette, Indiana, September 1975.

39. Peterson, Willis and Yujiro Hayami, "Technical Change in Agriculture," 44 p.

40. Plaxico, J. S. and L. G. Tweeten, "Representative Farms for Policy and Projection Research," Journal of Farm Economics, Vol. 45, No. 5, December 1963, pp. 1458-65.

41. Radosevich, George E., "Water Use Organization for Small Farmers," in H. H. Biggs and R. L. Tinner Meier, eds., Small Farmers Agricultural Development Problems, 1974, pp. 131-148.

42. Rogers, Everett M. and F. Floyd Shoemaker, Communication of Innovations, New York, Free Press, 1971.

43. Ruttan, Vernon W., The Economic Demand for Irrigated Acreage, Resources for the Future, Inc., 1965, 139 p.

44. Rydzewski, J. R. and C. J. N. Davey, "Irrigation Project Technology and Management," World Crops and Livestock, July/August, 1977, pp. 169-172.

45. Skogerboe, Gaylord V., et al., "Consolidation of Irrigation Systems: Phase I--Engineering, Legal and Sociological Constraints and/or Facilitators," Completion Report No. 52, Environmental Resources Center, Colorado State University, Fort Collins, 1973.

46. Taylor, David L. and William L. Miller, "The Adoption Process and Environmental Innovations: A Case Study of a Government Project," Rural Sociology, 43: 634-648, Winter 1978.

47. "The Relevance of Imported Management and Technology in Managing and Implementing Projects in Developing Countries, Kenya Approach," Discussion Paper, Prepared for presentation at Kenya Students' Conference, Harvard Institute of International Development, January 3-5, 1980.

48. Welch, F., "Education in Production," Journal of Political Economics, 78: 35-59, January/February 1970.